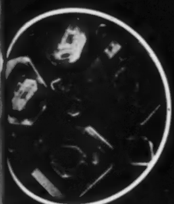
CHEMISTRY



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Why Build Your Instruments?

➤ THE INSTRUMENTS of science are like additional senses. They allow us to experience natural phenomena just as real as light and sound, for which we lack the instrumental equipment. Because our eyes and ears are tuned differently, we are deaf to some sounds, we are blind to almost all the spectrum of radiation, of which visible light is a very small part.

Yet there are many ways in which we can get around our limitations. We can find out indirectly more about what is going on in the universe than the wisest men used to realize. When objects are too small or too far away to be seen comfortably, we no longer blame the weakness of our sight. We fit lens combinations to produce a clear image for our eyes to see. When sounds are too faint, we amplify them with the aid of electronic circuits.

As new devices are tried out, new ways are often found to extend our perception. Photography began when a scientist first noticed that silver chloride darkens when exposed to light. Today by photography we map regions in both the ultraviolet and the infrared spectra. We can see pictures of things completely beyond our natural vision.

Study of electronic phenomena, which began with the invention of the electric light, has given rise to a great number of instruments, each capable of many modifications. Experimenting by amateurs has been the largest factor in the development of electronics, now including radio, television, radar, the new calculating machines, and many other signalling and recording devices still in the stage of laboratory tinkering.

Tracer chemistry, which allows the researcher to follow individual atoms through complicated life processes, is opening the door to vast new worlds of understanding. Development of new instruments parallels each step.

The ability to adapt scientific principles to the detection, measurement and recording of data is a skill of great importance. It promises great usefulness in mapping the mysterious but consistent realm around the corner from those sections of the universe that reveal themselves to our unaided senses. We need to conquer this knowledge and these skills for the betterment of mankind.

CHEMISTRY

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Scientific Instruments You Can Make

➤ YOUNG PEOPLE all over the country are becoming aware of the interesting glimpses they can get into the world of science by means of instruments they can build and use.

Every one of the great instruments of science was once hand made out of improvised materials. Students and amateurs today can follow in the footsteps of yesterday's pioneers in science, and produce their own instruments — with, of course, their individual improvements.

During the past fourteen years, in administering the Science Talent Search, Science Service has watched a procession of young scientists marching from secondary schools of the nation into college and on to take their places in the research laboratories. Building instruments is one of the favorite projects of these young people.

The National Science Talent Search, conducted by Science Service, awarding the Westinghouse science scholarships, endeavors to locate those boys and girls most needed to fill the ranks of creative scientist in the future.

For the past five years, through the National Science Fair movement, Science Service has encouraged other boys and girls, not just seniors, but all in junior and senior high schools, to turn their interest in science into a hobby. The exhibits they build to explain their interests to their schoolmates and to the public are a factor in the growing movement of youth into science.

The young people whose activities in science come into the spotlight of these programs, whether they come from East or West, North or South, city or country, show a surprising similarity of interests. One of the traits they all have in common is certainty that they can improve on the other fellow's method.

The descriptions of instruments in the following pages were written by the winners and honorable mentions of the recent Science Talent Searches. Some of the pictures were taken by the authors of the papers. Some were taken on Exhibit Night at the Science Talent Institute for the S.T.S. winners, in Washington. Some are pictures of exhibits at the National Science Fairs.

For good measure we have added descriptions of some famous instruments, written when their authors were also young experimenters.

This is not a how-to-do-it book. The young people whose work is shown here, with very few exceptions, did not follow published directions "from A to B." In most cases they read widely, and combined the most appealing methods from various sources. They learned while doing, and improvised as they went along. They were very cost-conscious. They salvaged parts from the most unlikely mechanisms, and turned them into "the very thing" to make their projects successful.

As ideas for other young people's projects, and jumping-off places for

➤ INSTRUMENTS *grouped around his telescope were made and used by Philip Robert Lichtman, Woodrow Wilson High School, Washington, D. C., a top winner in the Fifth National Science Fair, 1954.*

better ideas, these reports are offered as samples of the instruments many high school seniors have had great fun making and using. With appreciation to the boys and girls whose energy and patience went into making the instruments and writing the reports, this compilation challenges future young scientists: "Come on, let's see how you can do it better!"

▸ THE SPECTROSCOPE *box naturally takes on a triangular shape. This diffraction grating instrument with built-in camera was made by Latimer E. Dunn. His description of how he did it begins on page 11.*

The Spectroscope

▸ THE SPECTROSCOPE sorts out light waves according to their wave-lengths and spreads out the resulting rainbow so that the colors can be seen and measured conveniently.

Sunlight is a jumble of all wave-lengths. When these are sorted out a continuous band of colored light appears, with blue at one end and red at the other. These rainbow colors are the only part of the spectrum that the eye can see. There is much more of the solar spectrum, but special instruments are necessary to detect the other kinds of radiation which make it up.

The waves of light are sorted out by sending them through some other medium than air, such as glass, water, or other transparent liquid, and then back into air in such a way that their path is bent. A 60° prism spreads the light, and is often used to make a

spectroscope. Such a prism may be either of solid glass or built of thin glass plates, such as microscope slides, cemented into the shape of a hollow prism and filled with water or another transparent liquid. Other prisms, such as those with one 90° angle and two 45° angles, may be used, but they do not spread the light as much.

Another way to break up light into its different wave-lengths is by use of a diffraction grating. This is a strip of metal on which fine lines have been cut parallel to each other and very close together. Interference between light waves reflected from the edges of these tiny furrows in the metal is responsible for sorting out the colors. Diffraction gratings are expensive, because making them requires very exact workmanship. Replica gratings can be made from ruled originals.

The essential part of a spectroscope is the device to sort out the light waves. Next in importance is the light source.

Sunlight may be allowed to shine directly on the prism, or be reflected onto it. To analyze light from heated substances provision must be made in the instrument assembly for a burner or an electric spark-gap.

A Bunsen burner, which has a colorless flame, is useful to heat substances which vaporize and add their color to the flame. Salts of many metals do this, and the spectrum found in this way proves that the metal is present. Light given off by vaporized metallic salts does not show a continuous spectrum like sunlight, but consists of lines of different colors, with dark areas between.

Examination of the spectrum of an unknown substance is an important part of chemical analysis. The salt to be heated in the Bunsen burner flame is usually held on a small loop of platinum wire mounted in a glass handle. A holder for the wire loop may become part of the spectroscope arrangement.

Metals which do not color the flame may be made to show a spectrum in an electric spark-gap. Such an apparatus may be included in plans for building a spectroscope. A pair of simple dry cell batteries may provide the current for the spark, or more elaborate layouts may include transformers and condensers.

Students should draw freely on information about electric circuits which they will find in their physics text books. Every electric circuit should be planned out in detail and approved by the teacher or other expert before it is wired. Scientists do not run unnecessary risks with shock and fire hazards.

Many substances which do not show flame or spark spectra can be analyzed in the spectroscope in another way. This depends upon the fact that a solution of such a substance will absorb light of certain wave-lengths out of light which is passed through it. The missing wave-lengths will show up as black lines or bands.

The sun itself gave the original clue to this kind of analysis. The spectrum of the sun's light is crossed by many fine black lines, called Fraunhofer lines, after the man who first recognized them. The absorption which is their source is caused by gases in the comparatively cool outer atmosphere of the sun.

By matching these dark lines to the corresponding bright lines of chemi-

cal elements here on earth, astronomers can learn what elements make up the sun's outer atmosphere. In the same way they can analyze light from other stars, which are also suns similar to ours.

After deciding on the prism and the light source, the spectroscope builder will want to provide optical systems for focusing the light and magnifying the image. Two small telescopes are usually provided for this purpose. One, called the *collimator*, has one lens and, instead of an eyepiece, a slit which regulates the amount of light that is directed to the prism. The other magnifies the light which has passed through the prism. The eyepiece of this telescope is usually fitted with crossed hairs or "spider lines" which are useful in measuring the lines of the spectrum. The image of a scale can be introduced in such a way that it can be seen at the same time as the spectrum, and used in identifying the lines of the spectrum.

A camera can take the place of the observer, recording the spectrum on film or sensitized paper. The instrument then becomes a *spectrograph*. Photographic recording of spectra is interesting, because the camera can "see" wave-lengths invisible to the eye.

For work with absorption spectra, the image is sometimes scanned by a sensitive photoelectric device which is attached to a recording pen. The instrument draws a straight line, on moving paper, until an absorption band cuts off the light. Then a spring or magnet draws the pen at right angles, making a "pip" in the line, until reappearance of light makes the pen move back to its original place.

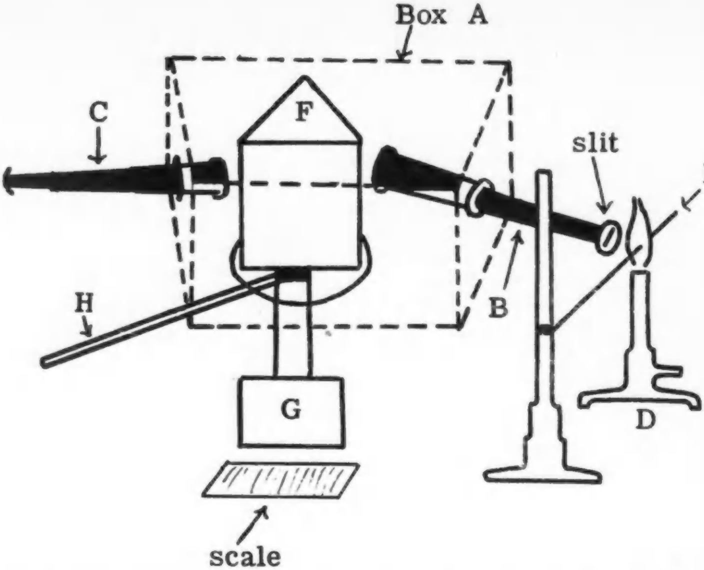
After the spectroscope has been designed, tried out and mounted, its builder will probably want to provide light-tight housing for it so that it can be used in daylight, and moved around.

The account of the first spectroscope, built in 1860 by Gustav Kirchhoff and Robert von Bunsen (the man who designed the Bunsen burner), is given here, with a drawing made from his design. There follow extracts from the Project Reports submitted by some Science Talent Search contestants whose projects included making spectroscopes. These give an idea of the variations on the spectroscope theme that these high school students have worked out.

The Original Spectroscope

CHEMICAL ANALYSIS BY SPECTRAL OBSERVATIONS, *by G. Kirchhoff and R. Bunsen. Poggendorf's Annalen, Band 110, 1860. Translated by D. B. Brace, published in "The Laws of Radiation and Adsorption." New York, 1901.*

▸ THE FIGURE represents the apparatus which we have used mainly in the observation of the spectra. *A* is a box blackened on the inside the bottom of which has the form of a trapezium and rests on three feet; the two inclined sides of the same form an angle with one another of about 58° and carry the two small telescopes *B* and *C*. The ocular of the first is removed and replaced by a plate in which is a slit formed of two brass cheeks which



➤ THE PRINCIPLES *of the spectroscope as developed by its originators, Robert von Bunsen and Gustav Kirchhoff, adapted from their original drawing.*

are placed at the focus of the objective. The lamp *D* is so placed before the slit that the mantle of the flame is intersected by the axis of the tube *B*. Somewhat beneath the point where the axis meets the mantle the end of a very fine platinum wire bent into a small hook and carried by a holder *E* passes into the same; on this hook is melted a globule of the chloride previously dried. Between the objective of the telescopes *B* and *C* is placed a hollow prism *F* with a reflecting angle of 60° and filled with carbon disulfide. The prism rests on a brass plate which can be rotated on a vertical axis. This axis carries on its lower end the mirror *G* and above it the arm *H* which serves as a handle to rotate the prism and the mirror. A small telescope is adjusted before the mirror which gives an image of a horizontal scale placed at a short distance. By rotating the prism we can cause to pass before the vertical thread of the telescope *C* the entire spectrum of the flame and bring every portion of the spectrum into coincidence with this thread. To every reading made on the scale there corresponds a particular portion of the spectrum. If the spectrum is very weak the cross-hair of the telescope *C* is illuminated by means of the rays from a lamp through a small opening which is placed laterally in the ocular of the telescope *C*.

Use of Available Optical Parts

John Allan Armstrong: The Design, Construction and Operation of a Prism Spectrograph. Mont Pleasant High School, Schenectady, N.Y. Winner, 11th S.T.S., 1952.

➤ I DESIGNED the instrument and housed it in a rectangular box in two sections. The optical system consisted of a slit, a 45° prism, a collimating system of two lenses, and a 35mm film holder. Three-quarter inch pine boards were used to build the case; the work was done in my basement shop.

Razor blades were taped over a hole in a 2"x3" steel plate, which could be bolted to the front-plate of the instrument. By building several plates carrying different openings, it was easy to change the slit widths.

The first spectrogram was made on 35mm Kodak Panatomic-X film, with a 14 watt fluorescent lamp as the light source.

It was necessary to design a system which would make use of the optics to which I had access. The system finally evolved is, to the best of my knowledge, unique in several aspects. The focusing is done by two separate lenses instead of the usual single lens. A focused spectrum is formed at two different points, i.e., at another point as well as at the photographic plate. The spectrum is enlarged several times within the spectrograph itself.

Two lenses (both color corrected) were obtained from a good pair of binoculars, and the enlarging lens from a Leitz microcamera loaned by a friend. With this optical system were incorporated an adjustment for the plate-tilt, and a fixture to carry a 5"x7" film-plate holder. As a light source, a 500 watt, quartz-enclosed mercury vapor arc was employed.

All the spectra investigated were obtained by gaseous discharge; first with the mercury arc, and then with two Geissler tubes containing neon and helium respectively. The Geissler tubes were excited by a 12,000 volt neon sign transformer.

The emulsion used was Kodak Contrast Process Panchromatic; it was processed with Kodak developer D-85, a para-formaldehyde developer of extreme contrast.

To evaluate this spectrograph and the optical system employed, it is necessary to consider the following facts: (1) The dispersion of the instrument varies from 50 A.U./mm (for lines in the red region) to 7.5 A.U./mm for lines in the region around 3650 A.U. (2) The resolving power varies from 520 to 790. These values compare very favorably with commercial instruments of the same size. (3) Although the actual value of the optics is much greater, the total cost of the project was less than $40.

On the other hand, due to the large light losses peculiar to the optical system, the instrument can be used to investigate only those spectra which can be excited for rather long periods of time.

My work is by no means finished; I have, however, found the answers to several of my questions. First, it is possible to build a workable prism

spectrograph inexpensively. Second, there is an optical system different from the usual type which is quite satisfactory. Finally, I have gained an insight into the methods of spectroscopy that will be very valuable in applying spectrographic data to physical theory.

The Carbon Arc

Anthony Izzarelli: Direct Observation with the Spectroscope and the Spectrograph. Fairfield College Preparatory School, Fairfield, Conn. Winner, 13th S.T.S., 1954.

➤ THE SIMPLE but very efficient carbon arc appealed to me. I set up the carbon arc spectroscope on a wide and steady table so that I could work with it more easily and also partially eliminate the off-focused readings that often result when the apparatus is shaken.

I used two powerful converging lenses to concentrate all the light I could onto a small slit of 1.7 mm width. I placed a focusing lens whose focus point is 29.8 cm in front of a 60 degree flint glass prism. Then I chose a white cardboard box as my observation screen. I carefully measured off a scale in millimeters onto the screen with a magnifying glass and sharp punch. To focus the spectrum I placed two plain carbon rods into the arc and, by trial and error method, I succeeded after many attempts to get a wide continuous spectrum on my screen.

Since I used an open screen, I had to work in complete darkness. This made it difficult to take notes and move freely, but I easily remedied this difficulty by using a flashlight.

In order to get a bright line spectrum with a carbon arc, I found that I could obtain better results if I drilled the two carbon rods and placed the volatile substance into the small holes. This placed the volatile substance in such a position that the vaporizing substance, caught by the brilliant light of the carbon arc, appeared as a bright line spectrum. I used sodium sulfite. The spectrum lines were too wide. I made my own adjustable slit with a safety-razor blade and, by closing the slit to .9 mm, I was able to get sharp and distinct spectrum lines. Other salts were used to compare the spectra of the elements composing them. To determine the wavelengths of the readings I obtained from the tests, I plotted a graph, using the mercury lines from the mercuric oxide test as my standard wavelength. Since the other readings did not fall exactly on the curve, I knew that my figures were incorrect and this error came into my calculations because, at that time, I didn't know that a change in focusing setup would lead to error. I was changing the focusing lens and the prism at every test so as to obtain better results.

These tests were done on an open screen, because it is my intention to make permanent records of these spectra by putting a photographic plate on my screen where the spectra fall.

The Rowland Circle

David Todd Hammond: Design and Construction of a Diffraction Grating Spectrograph. P. A. Allen High School, Bluffton, Ind. Honorable Mention, 12th S.T.S., 1953.

➤ THIS SPECTROGRAPH is principled upon the Rowland circle, wherein the slit, the concave reflection grating, and the photographic plate are mounted on a circle determined by one-half the radius of curvature of the grating. The instrument is designed to subtend only that arc of the Rowland circle actually involved, thus providing for a minimum of bulkiness (figures 1 and 2). Constructed of quarter-inch plywood and painted dull, non-glossy black on the interior, the body resembles a miniature grand piano The radius of curvature of the grating is 1000 mm, fixing the radius of the Rowland circle at 500 mm.

This adaptation of the Rowland circle (figure 2), known as the Eagle mounting, was the most practicable as it dispensed with any additional optical pieces (a collimator lens and/or a reflector mirror) which would only multiply the probability of adjustment error.

As the spectrograph serves essentially as a camera, the instrument was rendered completely light-proof, not only to prevent film exposure, but also to eliminate extraneous spectra arising from stray light. A suitable resilient material could not be secured to line the interior seams and joints. So that the work might be continued, a temporary lining of adhesive and dark masking tape on the exterior seams sufficed. When it can be obtained, a resilient spongy rubber stripping will line the interior. A partition of black construction paper was inserted between the slit and photographic plate to prevent any light from the slit from falling directly on the film.

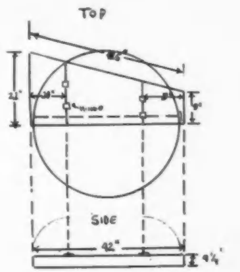


FIG. 1 SPECTROGRAPH DESIGN

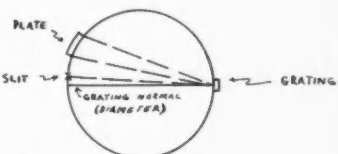


FIG. 2

ADAPTATION OF ROWLAND CIRCLE

The grating was supplied by the Jarrell-Ash Company of Boston, Massachusetts. Industrially unsuitable, the piece was furnished gratis. The replica grating, i.e., a colloidion cast of a master grating and mounted on a silvered glass base, was a reject because of an air bubble in the base and a large chip of the base near the edge. This one meter grating has a ruled surface of approximately 1.5 inches

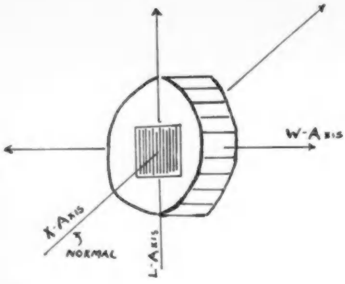


Fig. 3 Grating Axes

square, with 15,000 lines per inch. In mounting, it is necessary to align the grating with respect to the three mutually perpendicular axes (fig. 3).

This piece was mounted within the spectrograph to facilitate forming a temporary shutter, composed of a multi-layered adhesive flap. This was located on the exterior and was easily operated by hand.

A carbon arc, volatilizing finely-divided samples of metals, comprised one source of light. Power was furnished for this by a reactor unit which supplied an arc current of 7.5 to 10 amperes on a 110 AC line. One electrode, placed above another, is lowered to make contact with the other. Heat generated at this point ionizes surrounding air, permitting an arc to be formed when the electrode point is raised. The sample emits its characteristic spectrum in this arc. A small carbon pellet with the sample placed in the hollowed-out top is set on the bottom electrode. This arrangement permits an arc to be achieved more easily when using low voltage. The circuit was controlled by a fused switch panel. A problem arose in maintaining manually a steady arc; this was overcome somewhat by practice, but a mechanical means of control is to be installed for a permanent arrangement.

A platinum wire, which was dipped in a salt solution of a metal and held in the flame of an alcohol burner, provided another light source. Although

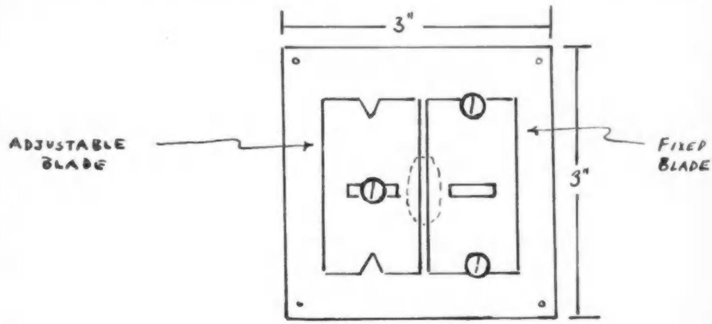


Fig. 4. Slit Details

the flame is not so intense as the arc, the handling of the wire was simpler.

A bright two cell flashlight was employed as a third light source to emit a line spectrum of the element tungsten.

The plate consists of 35 mm film loaded on a film track conforming to an arc of the Rowland circle. Two copper strips, each doubled over and bolted on a curved wooden block, guide and hold the film in place. This plate is thirteen inches long; a strip of 35 mm film this length is cut from a bulk roll. Best results have been obtained from Kodak Panatomic-X film. The camera is loaded in a darkroom.

Dispersion of the Grating

Latimer E. Dunn: Design, Construction and Use of a Concave Diffraction Grating Spectrograph and Accesesories. Garfield High School, Terre Haute, Ind. Honorable Mention 12th S.T.S., 1953.

➤ In this experiment a modified Rowland mounting, in which the slit, grating, and spectrum all lie on the circumference of a circle with a diameter equal to the focal length of the grating, was used. When the slit, grating, and spectrum are installed in a light tight camera box it naturally takes on a triangular shape. This triangular camera box plus a separate source unit compromises the usual concave grating setup. That type of setup, however, seemed unnecessarily cumbersome to me. It occurred to me that perhaps the two could be effectively combined by setting the triangular camera on end and building a source-containing cabinet around it.

The grating to be used was chosen after careful consideration of available gratings from the standpoint of resolving power, price, focal length, and dispersion. Several gratings were acceptable from the standpoint of the first three as presented in catalogues, but nowhere could any statement be found about their dispersions. The dispersions of the various gratings were found by experimentation with a standard mathematical formula. The direction θ in which any particular wave length λ will be thrown is given by the formula

$$m\lambda = \frac{A}{N} (\sin i \pm \sin \theta).$$

Where i is the angle of incidence and θ the angle of emergence, both measured from the normal. A is the linear aperture of the grating, N the total number of lines and m the order used. After some work with this formula the desired result, a 10″ first order visible spectrum, was obtained using 13° as angle i. A Wallace replica was then ordered from Central Scientific Co., which had 15,000 lines and a focal length of 106 centimeters. Wallace replicas are made by taking a collodion cast of an original grating and then depositing it on an aluminized concave mirror.

Inasmuch as the basic design was completed and the grating was ordered, dimensions for the camera box and the cabinet could be worked out. The finished instrument was to be 58″ long, 23″ high, 13″ thick, and weigh less than 100 lbs. The light source unit would be an integral part of the in-

strument, a compact, self-contained unit.

Construction was begun with the camera box, which was then secured to a plywood base plate. The slit may be adjusted for focusing by sliding it in and out like an eye piece of a telescope. The slit has one fixed and one movable jaw so that the aperture may also be varied. The grating is adjustable in several directions also. These adjustments provide for varying the angle of incidence, the resulting dispersion, and the order which will be thrown on the film. As soon as the camera was finished a test exposure was run to be sure that everything was properly arranged on the Rowland circle.

Cabinet construction was facilitated by cutting pieces of plywood and fastening them together with bolts and angle braces. The bolts were all countersunk in order to have a smooth finish throughout. Panels and doors were then added and the instrument was painted.

Since the cabinet was now completed I began the wiring. It was decided to provide the instrument with one high voltage discharge for use with gaseous spectrum tubes and two A.C. arcs of different powers. Two arcs were supplied so that experiments on excitation at different energy levels could be carried out. Circuits were designed and diagrams made. Due to the lack of appreciable reactance or inductance, values for the resistances could be figured out by using Ohm's formula

$$E = I\ R$$

and the power formula

$$P = E\ I$$

where P is the power in watts, E the voltage, I the current in amperes, and R the resistance in ohms. The actual wiring gave little trouble and was completed in one evening. The instrument was provided with interior illumination, panel lamps, and a safety fuse for convenience, safety, and appearance.

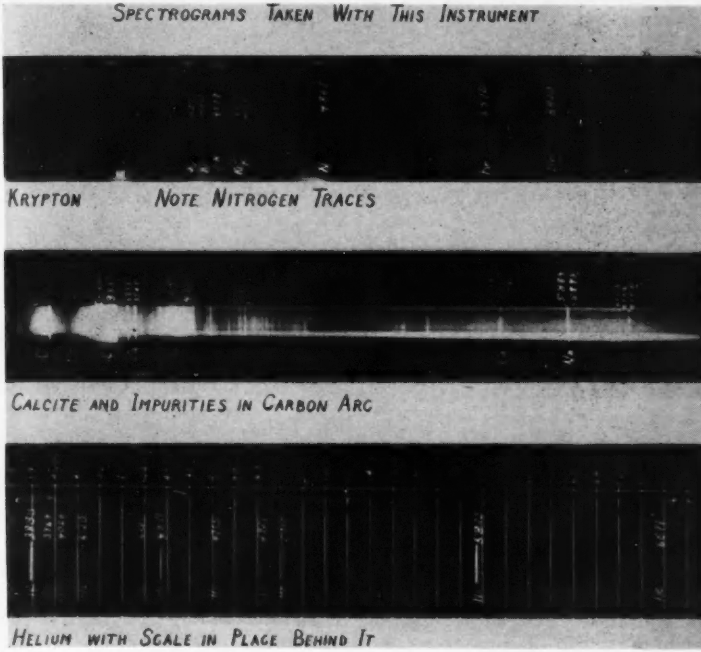
Immediately after the wiring was completed the entire instrument was painted with a high gloss enamel and door handles and switches were put in.

The important accessories, a film holder and a negative viewer, were needed before the instrument could be effectively used. The viewer was quite simple, but the film holder proved more of a problem. It had to be light tight, curved to fit the focal curve, and have a darkslide. It was made by laminating 1/16# sheet balsa wood and using the curved film plane itself as a mold.

It was decided that a gaseous element with relatively few lines should be used in calibrating the scale for the instrument. Helium was chosen.

As soon as a good helium exposure was obtained the division of the scale was begun by using as reference points He 3888 and He 5875, which were chosen because of their separation of approximately two thousand angstrom units, (Å), an Å being 1×10^{-8} cm. After the distance had been marked off into divisions of 50 angstroms each with a pair of dividers, I attempted to check out the rest of the helium lines.

Later, with the aid of a sodium vapor (plus argon) lamp a still more accurate scale was worked out using Na 3302 and A 6604 as reference



➤ THE INSTRUMENT *built by Latimer E. Dunn, which is shown on page 3, photographed these spectra of several elements. The builder worked out a way to label his spectrograms, by writing on the glass covers.*

points. This scale was transferred to a piece of meso-plate, a translucent vinyl ground glass substitute, which is laid on the face of the viewer. This scale has been used on exposures of krypton, neon, and a few arc exposures and has shown itself to be accurate within a few angstroms.

All exposures, which ranged from 7 seconds to 2 hours, have been made on Kodak 35 mm, Plus -X film. Plus X was chosen because it has moderate speed, good resolving power, low cost, and is easily obtained. Most of the pictures have been developed for ten minutes at 70° in F R Super X 33 developer and fixed for four minutes in a solution of seven parts water to one part F R Rapid Fixol. However, some experimentation has been done with forced development and rapid fixation in an attempt to cut operating time to a minimum.

Curling, which was due to the heat of the viewer, was overcome by sealing each negative between two long, narrow, rectangular pieces of glass much as are coloı slides.

Three Slits

Alan Frederic Haught: Spectrographic Determination of Intermediate Products in Catalytic Reactions—Apparatus. Bethesda-Chevy Chase H. S., Bethesda, Md. Winner 13th S.T.S., 1954.

➤ I FOUND that for absorption spectroscopy of inorganic reactions the most useful and practicable region of the spectrum is from the near ultraviolet to the near infrared, i.e., from 2000 to 10,000 A. For the analysis of catalytic reactions, I built a concave reflection grating spectrograph because of its many advantages. I selected the modified Abney mounting of the components as the best for my purpose. This mounting uses two or more slits, each one casting a different portion of the spectrum on the photographic plate. I use three slits, one covering the region from 2000 to 6000 A, another covering from 4000 to 8000 A, and the third from 6000 to 10,000 A.

I constructed the entire spectrograph and made all parts except the grating itself, using stock metal, plastics and masonite. I drew up several preliminary layouts of the instrument and designs of major parts before developing final plans. Converting plans into reality involved many difficulties. Bending angle steel to form a rigid framework of accurate size and shape taxed the facilities of my home workshop. It was a major problem to make a light tight, movable, curved plateholder, easily removed and replaced, yet simple enough to load and unload in complete darkness. The problem of making a slit holder, which could be permanently positioned on the frame in proper relation to the grating and yet be adjusted for focal length, was solved by using sliding telescope tubing in a rigid mount. Despite problems and difficulties, however, I built a workable, practical and comparatively inexpensive spectrograph for my experiments.

The movable plateholder and its mechanism, the adjustable grating mount, and the adjustable slit are of my original design. The plateholder is made to take 35 mm film and will photograph spectra 25 cm long. It is moved by a screw mechanism so that five spectra can be photographed on each film. The grating mount has six screw adjustments for setting the grating in alignment by rotation on its three axes and provision is made for focusing the spectrum on the plate. The slit, made of two razor blades held under spring tension and adjusted for width by two screws, is mounted in a telescoping tube which permits focal adjustment.

To hold solutions for spectroscopic analysis, I made several absorption cells with quartz end plates for transmission of ultraviolet light. Because dilute solutions were used, a cell with a relatively long path, 7.5 cm., was used for all experiments.

Light source posed a problem. The available carbon arc and metallic arc lamps, which produce light down to approximately 3000 A and 2500 A respectively, were difficult to keep in adjustment for time exposures. Test spectra of the solutions to be used in the experiments, however, showed that their transmission dropped off at 3000 A or above. Consequently, instead of the unreliable arcs, I used a photoflood bulb which produced constant light in the region required.

➤ ORION *on a hazy night shows up the relative brightness of the stars in this well-known constellation. Peter Lauritzen made this striking photograph with his wide-angle camera. His account of his stellar photography begins on page 23.*

Astronomical Instruments

➤ FOR ABOUT a generation, young astronomers have been building their own telescopes. They grind concave reflecting mirrors of the type recommended first by Sir Isaac Newton. The mirror, ground first to a spherical surface, then corrected to the form of a paraboloid, reflects all light waves in a parallel beam. This avoids the problem of chromatic aberration, the focusing of light of different colors separately, which makes colored rings around the image. This is especially troublesome in astronomical work, and Newton believed the difficulty insoluble when lenses are used. Modern developments in lens making, using combinations of different kinds of glass, have produced lenses without chromatic aberration. But the Newtonian telescope remains a popular design. The light is reflected first from the concave mirror, then, by means of a diagonally-placed plane mirror, to an eyepiece at the side of the tube.

After grinding a six-inch mirror and assembling a telescope, many amateur astronomers join the program for estimating the brightness of variable stars, under the auspices of the American Association of Variable Star Observers, Cambridge, Mass.

Making the Telescope

Donald Prescott: Constructing a Telescope. Phoenix Union High School, Phoenix, Ariz. Honorable Mention, 12th S.T.S., 1953.

➤ LOOKING at the undiminished brilliance of the heavens through your own handmade telescope is a thrill that will stay with you forever. My project was the building of a modest six-inch F 8 reflecting telescope complete with accessories.

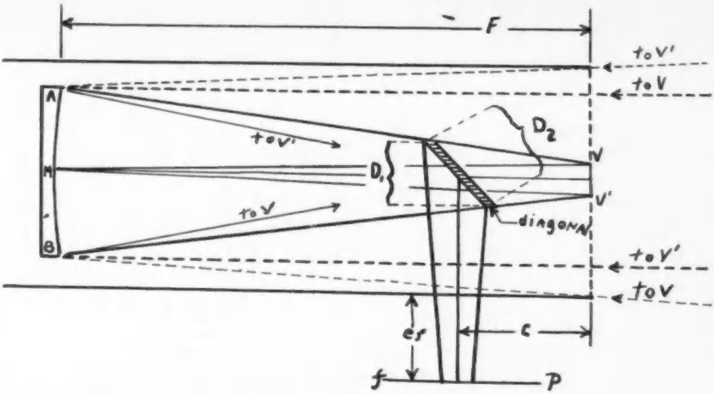
Building a telescope comprises grinding the mirror down to a rough spherical surface, polishing to a parabolical surface, installing the diagonal and lenses, and constructing the mount. I obtained the six-inch pyrex disk and tool complete with the necessary abrasives from an optical supply house. Other necessary materials were obtained locally and the entire list is given at the end of this account.

The tool is secured to a wooden plank which in turn is bolted to a metal drum. By placing the charge of coarse carborundum on the tool and carefully laying the mirror disk on that, we can begin the rough grinding. We work each charge of carborundum for five minutes and grind through 12 charges. The grinding technique is to begin the stroke by placing the center of the mirror one-half inch from the edge of the tool, and using a stroke equal to one-third the diameter of the mirror disk. After six or eight strokes, rotate the mirror on the tool about 30 degrees and move yourself about 30 degrees around the barrel in the opposite direction.

When this zone is ground to fit a template whose arc is the arc of a 196-inch circle, we move the mirror one-half inch closer to the center of the tool and grind in the same fashion until the next zone fits the template. This process is repeated for each half-inch zone until the curve extends across the mirror whose focal length is about 49½". With the 5 finer grades of carborundum we use the same technique of grinding as with the coarser one except that our stroke begins with the center of the mirror over the center of the tool. When using the last two grades, we place the tool on top of the mirror half of the time in order to remove the pits on the edges of the mirror.

Now we have made the surface of the mirror into a rough spherical curve, and it is necessary to polish it to a parabolical curve. For this purpose we shall need to make a pitch-lap to hold the fine polishing abrasives. Mix seventy-five per cent pitch and twenty-five per cent rosin and heat until the mixture when cool is fairly hard but not brittle. Pour the mixture onto the tool which has been collared with a strip of heavy paper to a depth of one-fourth inch. Allow to set and press channels one-eighth inch wide and one inch apart across the surface of the lap to form squares. Shape the warm lap by pressing with the mirror until it conforms. Trim and coat with beeswax.

Before each polishing operation heat the lap and press with the mirror and a 20-pound weight for fifteen minutes. Polish for twenty minutes and then cold press for ten minutes. The polishing technique is the same as that of grinding except that we



➤ REFLECTING *telescope is a favorite instrument for amateur astronomers to make. Donald Prescott tells how he made his and how he mounted it for use.*

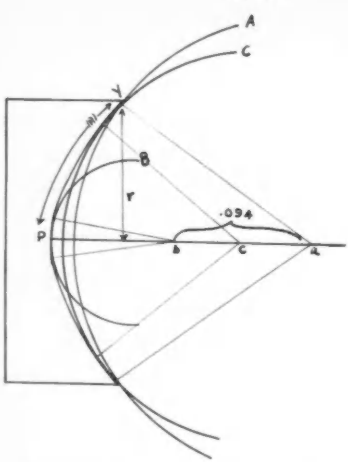
rotate the mirror with every other change of position. The polishing operation usually takes from three to six hours, but my mirror required ten hours because some pits complicated matters.

After seven hours of polishing there were still some pits in the mirror so I returned to emery 305 and ground for two hours. In the end I found out that the so-called pits were myriads of tiny bubbles in the glass. These can be detected by holding the mirror so that the sun shines through the thick part of the glass, or by placing the mirror under a microscope and shining a strong light under it from an angle. Any pits will have a shadow on one side of them while bubbles have no shadows. When the mirror is fully polished, the spot of a magnifying glass held in the sun can barely be seen on its surface.

To remove the turned-down edge developed under polishing, we polish for five minutes and cold-press for ten, testing at frequent intervals until the edge is smooth under the knife edge test. To correct an oblate spheroid, use a one-half diameter "W" stroke and overhang the edge of the mirror to the boundaries of the central hill. To correct a hyperboloid, the knife edge is set at the center of curvature of the edge-zone, and the edge is planed down with a short stroke until the edge shadow is the same depth as that of the center. The resulting figure is an oblate spheroid which must be corrected as above.

Most of the polishing is aimed at changing the surface from the spherical curve into a parabolical curve in order to focus all the light waves at a single point. The center of curvature in any mirror is equal to twice the focal length. The distance between the center of curvature of the mirror's center zone and the point of intersection with the axis of the normal to

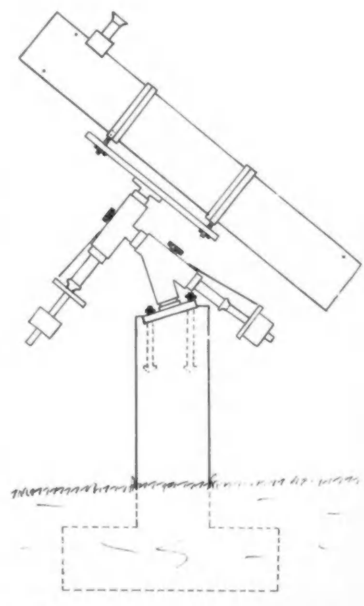
Fig. 2.



➤ How the paraboloidal *mirror differs from the spherical. The parabola reflects parallel beams of light, an advantage in focusing the image in the reflecting telescope.*

any other zone as seen from a Foucault device is equal to $r^2/2R$, where r equals zonal radius and R equals radius of curvature of the center zone. This value for a six-inch F-8 mirror is .047". By locating the center of curvature of each zone and measuring the distance between them, we can find how closely the figure of the mirror approaches a paraboloid.

Since the lamp of the Foucault device is stationary, the difference of the centers of curvature between the zones is doubled and the correction of the mirror has a value of .094". The actual separation between the curved surfaces of a spherical and a paraboloidal mirror of the same focal length is equal to $r^4/8R^3$. This is equal to .0000114 at the edge of the mirror or one-half wave length of light. To form a perfect image, the light rays from an object must be from one-quarter to one-half wave length of light apart in the focal plane. Since the light waves from a reflector are reflected back, the correction must be one-fourth wave length in order to meet the more tolerant one-half wave limit. Therefore the difference between the sphere and parabola must be .0000055".



➤ Pipe fittings *and home-made bearings complete Prescott's telescope. He finds great satisfaction in viewing stars and planets through the instrument of his own construction.*

The Foucault device magnifies 100,000 times, and the mirror must be correctly polished within 55/114 of r^2/R. The testing device enables us to see this correction as between .05" and .14". The sphere is brought to a parabola by using a one-half diameter "W" stroke; moving around the barrel 30 degrees and rotating mirror after each change of position. Long periods of pressing and frequent testing are necessary so that the curve may be regular and free from astigmatism.

Next to the mirror, the diagonal is the most important part of the telescope. The size of the diagonal is $1\frac{3}{16}$" by $1\frac{5}{8}$", or about $1\frac{1}{2}$ inches square for a prism.

Since the construction of the mounting is entirely of a mechanical nature, I am including only a drawing. It is made of pipe fittings which can be bought anywhere, and babbit metal bearings which I poured myself.

Required Materials

1. 6-inch pyrex mirror blank
2. 6-inch plate glass tool
3. Grinding materials:
   A. Carborundum No. 80
   B. Carborundum No. 120
   C. Carborundum No. 220
   D. Carborundum No. 400
   E. Alundum No. 600
   F. Emery No. 305
   G. Cerium Oxide
4. Pitch
5. Rosin
6. Beeswax
7. To make or buy:
   A. Template
   B. Testing stand and rack
   C. Channeling Tool
   D. Grinding stand
   E. Foucault testing device
   F. Turpentine
   G. Carborundum stone
   H. Small paint brush

Celestial Photography

Jonathan Darby Lubin: Celestial Photography With a Home-Made Six-Inch Reflecting Telescope. Tottenville High School, Staten Island, N.Y. Winner, 12th S.T.S., 1953.

➤THERE ARE three ways of taking photographs with a telescope. The first, shown in fig. 1, which is used by all large telescopes, places a plate at the focus of the mirror. In the second, shown in figure 2, an ordinary camera is put up to the eyepiece of the telescope. This is exactly what happens when the eye looks through the telescope. In the third, shown in figure 3, the eyepiece is drawn out a little, and the plate is put behind the eyepiece a few inches, where the light rays come to a focus. The disadvantage of the first method is that the image of the moon would be only about .44 inches with my 49-inch focus telescope, and other objects would have proportional sizes. I therefore decided not to use this method. It was more difficult to decide between the second and third methods. However, Harold A. Lower, in "Amateur Telescope Making," states that "camera lenses do not work nearly as well as a good positive eyepiece." Also, the magnification can be changed in the third method simply by moving the plate farther from the ocular and making a small change in the adjustment of the eyepiece. The second

method offers no such advantage, except by changing eyepieces.

A simple way to hold the plate at the proper distance from the ocular is to attach a plate camera to the eyepiece tube by an adapting ring. This is shown in figure 4. The focusing devices on the camera and on the telescope are used for adjusting the size of the image and focusing it, respectively. A ground glass must be used for getting accurate focus.

Until I obtained a motor drive, I could take pictures of only the moon, because its great brightness allowed exposures as short as one second.

I purchased an 1800 RPM synchronous motor which was already geared down to 2 RPM. It remained to gear it down further so that the telescope would follow a star perfectly.

Since the sidereal day is 86,164 seconds long, I would have to make the telescope move one revolution in this time, except for one factor. The regular atmospheric refraction causes a star to rise earlier and set later each day. Consequently, a star's apparent motion is slower than the rotational speed of the earth would indicate. According to John M. Pierce in "Amateur Telescope Making," Professor E. S. King of Harvard advised that for ordinary purposes, the telescope should be set about one second per hour slower than usual. This would give one revolution in 86,188 seconds. But I decided to make this 86,190 so that calculating a train of gears would be easier. The prime factors of 86,190 are 17, 13, 13, 5, 3, 2. Because I already had a 100:1 reduction on the right ascension control, I had to have one revolution every 861.9 seconds. To get this from the shaft of the motor, which makes one revolution every 30 seconds, I had to figure out a gear train with a reduction of $\frac{86,190}{100 \times 30}$ or $\frac{17 \times 13 \times 13.}{100}$

The gear train I finally chose was

$$\frac{26}{10} \times \frac{26}{8} \times \frac{32}{8} \times \frac{17.}{20}$$

But the Boston Gear Works, from which I purchased all my gears, does not stock any small 17-tooth gears. However, in my cellar there was a 17-tooth helical gear from an old spring-driven phonograph with a 96-tooth gear to match. Because of the difficulty of getting a 20-tooth helical gear to mesh with the 17-tooth gear, I used another 96-tooth gear in the train. Now the train was like this:

$$\frac{26}{10} \times \frac{26}{8} \times \frac{32}{8} \times \frac{96}{20} \times \frac{17.}{96}$$

At present I am working on several improvements: reduction of vibration by eliminating as much as possible the looseness and play in the telescope mounting, and correction of any errors of construction in the motor drive, particularly in its gear box. In this way I hope eventually to improve the performance so that I can make long exposures and thereby record faint objects.

One respect in which my telescope differs from most others is in the mounting of the right ascension slow motion control and the right ascension dial. On most mountings, there is a fixed pointer and the setting circle is attached to the polar axis. The slow motion worm wheel and its friction sleeve are entirely independent of these. With this, when setting the telescope for a star, the right ascension is not dialed, but rather the hour

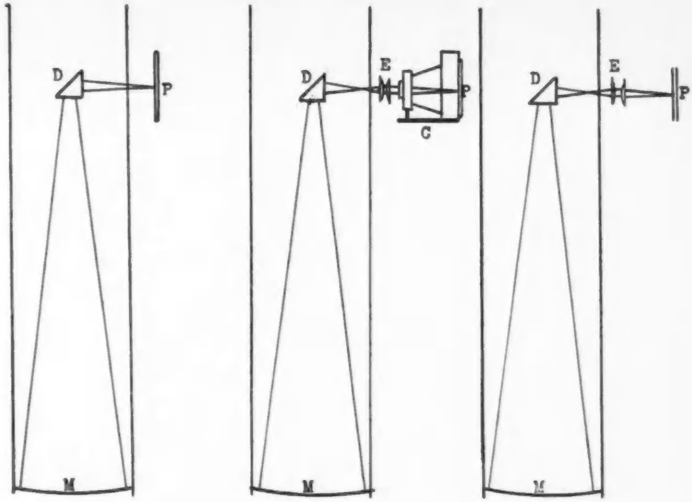


Fig. 1 Fig. 2 Fig. 3

C - Camera
D - Diagonal
E - Eyepiece
M - Mirror
P - Plate

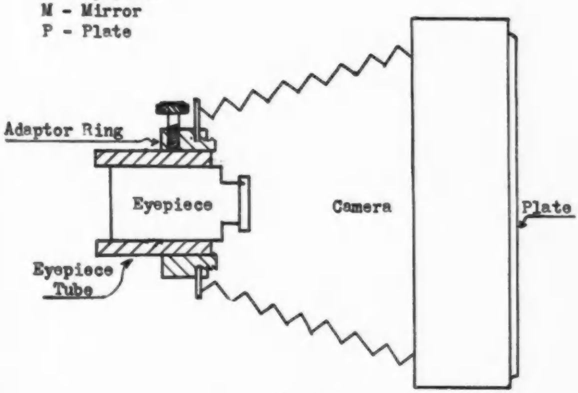


Fig. 4

➤ THREE WAYS *of taking pictures with a telescope are illustrated here by Jonathan Lubin. He chose the third method for his project, in which the photographic plate is put a few inches behind the eyepiece of the telescope, as diagrammed in Fig. 3. In Fig. 4 he shows how he built an adapter to connect his camera to his telescope.*

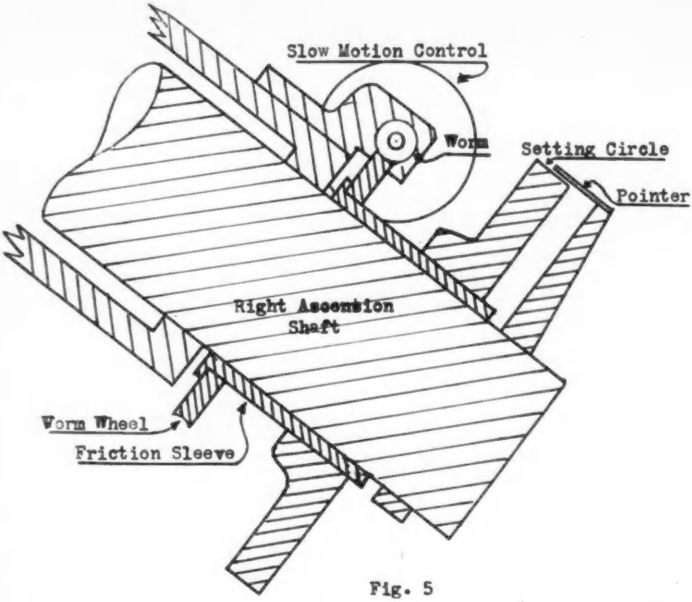


Fig. 5

➤ Mounting *of the right ascension slow motion control and the right ascension dial on Jonathan Lubin's telescope. The arrangement allows him to set the circle to the right ascension of the star.*

angle of the star, which is the difference between the sidereal time at the moment and the right ascension of the star.

With my arrangement, which is more elaborate, there is a friction sleeve on which is mounted a worm wheel and setting circle. The pointer is attached to the polar axis. The arrangement is shown in figure 5. When the shaft is moved, only the pointer moves, as it is fixed to the shaft, while the worm wheel and setting circle remain stationary. But when the slow motion worm is turned, the whole assembly moves together, and there is no change in the reading on the circle. One advantage to this arrangement is that I can set the circle to the right ascension of the star, instead of having to make beforehand a time-wasting calculation involving sidereal time. I got the idea for this arrangement from a letter by Hans Pfleumer in the November, 1951 issue of "Sky and Telescope."

The telescope and mounting can be assembled and oriented within twenty minutes. When taken apart, it is easily portable.

Wide Angle Photography

Peter Laritzen: Wide Angle Astronomical Photography with a Conventional Camera. Rock Island High School, Rock Island, Ill. Honorable Mention, 11th S.T.S., 1952.

➤ ONE INTERESTED in astronomy can see many objects with the unaided eye. The telescope makes it possible for him to see stellar bodies greatly magnified and also some which are much fainter. The telescope, however, has a very narrow field and the relative positions of faint objects can not be observed. With wide angle astronomical photography many otherwise invisible star clusters, nebulae, planets, and other objects may be located and studied.

To take good pictures of stars, long exposures are needed, making necessary a good clock drive or slow motion device with an equatorial mounting. The camera should have a fast lens with a wide field and good definition. A long focal length lens will give more magnification, but the camera will be much more bulky and the field of view may be narrowed. For the combination of speed, wide field, and good definition, the Schmidt camera would be ideal, however, a Kodak Reflex I. was used in this experiment. Of the available cameras it most nearly met the requirements.

This camera was mounted on a telescope equipped with a synchronous motor clock drive. The telescope itself was used merely as a guide. The clock did not follow the stars exactly, and there was no way in which this error could be accurately corrected, other than moving the telescope by hand in right ascension or declination. This could not be done smoothly. With this setup the time of exposure was limited to about twenty minutes. A few exposures as long as forty-five minutes were tried, yielding negatives in which the stars were definitely trailed. Since these trails were irregular, this has been partially attributed to an insecure camera mounting.

During February and March 1951 about eleven pictures were obtained with this equipment. The exposures ranged from ten to twenty minutes on Kodak Super XX film at f:3.5. The square $2\frac{1}{4}''$ by $2\frac{1}{4}''$ negatives, covering a field of forty degrees, were developed in Ansco 17 developer for about seventeen minutes. The prints were made on Kodabromide N-2 paper and developed in Kodak D-72 developer. The photographs gave the sky the same appearance as seen when viewed through ordinary binoculars except these photographs covered a much wider field. On them were found many well-known star clusters and nebulae, many of which are invisible to the unaided eye. *Norton's Star Atlas* was used to identify these objects. The milky way was resolved into many faint stars. The double cluster in Perseus is one that came out especially well as many stars in both of the two clusters were resolved. The stars Mizar and Alcor in Ursa Major were well separated. Even the planet Uranus was located on one photograph.

The charts could be used for constellation study, but the difference in

each star's apparent magnitude is not easily seen. A few of the pictures were taken on a night that was slightly hazy. This diffused the light of the brighter stars, making the differences in magnitudes more obvious. This same effect could be achieved by using a diffusion screen over the camera lens. Considerable coma at the edge of the photographs was due to the limitations of the lens of the camera. The faintest stars thus recorded were of the seventh magnitude.

Work has been started on a different guiding and tracking mechanism, so that longer, better controlled exposures can be made. A motor from a Seaberg traffic light combined with a gear train obtained from an old phonograph was adapted to driving a portable equatorial mounting. A 3½ inch telescope was provided with crosshairs for guiding and placed on the mounting. Provision was also made for fastening various cameras. With this mounting it is possible to regulate the speed of the motor. Also errors can be seen and corrections accurately made in declination as well as right ascension.

With long exposures one should obtain stars as faint as the ninth magnitude and other faint objects. Other refinements to be tried include: colored filters in combination with various photographic emulsions may show color differences among the stars and nebulae; polaroid filters may be used. yet it is doubtful whether this will have any effect although some nebulae are thought to give off polarized light; and finally, other cameras may be used to produce a wider field or even more magnification.

Observing the Sun

Paul W. Hodge: A Small Spectroheliograph. Snohomish High School, Snohomish, Wash. Honorable Mention, 11th S.T.S., 1952.

➤ WHEN George Ellery Hale took the first photograph of the sun in the light of a single element in 1892, he found a new and extremely important field of solar research, which might be called "spectroheliography." Since the construction of Hale's small spectroheliograph at his Kenwood Observatory, many large instruments have been built. The principal ones are at Mt. Wilson Observatory, McMath-Hulbert Observatory, Yerkes Observatory, Observatory of Meudon near Paris, and the Observatory of Arcetri in Italy.

After reading about these instruments in Menzel's "Our Sun" last spring, I decided to build a small spectroheliograph so that I might gain a more thorough background for the science in which I wish to do research—astronomy. Because of the fact that this involved the study of the sun, our nearest star and the only one that can be studied in fine detail, I felt that this would be the most valuable precollege project that I might undertake.

The only detailed information that I could find about the design and construction of such an instrument was an article by Hale in *Amateur Telescope Making*. At the Seattle Public Library I was able to find in astro-

nomical journals many articles describing the various instruments and their current tasks, but although they were helpful in other ways, they did not describe either design or construction.

I also discovered that if any part of the instrument, except three of the lenses and the two prisms, were to be purchased, they would be either extremely expensive or completely unobtainable. Therefore all of the parts were made by myself with the exception of the clockwork, which was built by Mr. Stanley Willhight, an interested watchmaker of our town.

The horizontal telescope design described in *Amateur Telescope Making* was found to be undesirable for my instrument because of the large number of trees in our back yard, so I decided to bend the optical train in the middle, using a tower to compete with the trees. This tower also makes it possible to have a much more compact instrument. A site was then chosen that would allow the sun to be studied from sunrise to sunset at any time of the year.

My design called for two structures: a twelve-foot tower for the coelostat and telescope and a small building to hold the spectrograph box.

The coelostat, which is on a platform at the top of the tower, consists of two plane first-surface mirrors, 4 x $3\frac{1}{2}$ x $\frac{1}{8}$ inches in size. The first, moving mirror is mounted on an equatorial mounting at an angle which corresponds to the latitude of Snohomish and is driven by means of clockwork and gears at the rate of one revolution every forty-eight hours. In order to be adjusted to the changing declination of the sun, this whole arrangement is moved north or south, depending on the season.

In this way the sun's light is kept constantly on the stationary second mirror of the coelostat. This mirror is kept directly above a hole in the center of the platform so that the sun's rays may be directed either to the 13.5 foot focal length lens, the 6 foot focal length lens, or directly to the diagonal for use with the 7.1 foot focal length mirror. The latter was the optical arrangement used for the initial experiments for focusing and other minor adjustments.

The concave mirror, which is eight inches in diameter, masked to three inches because of the intensity of the sun's light, is the mirror of an equatorial telescope. It is placed at the base of the tower with another small mirror so that an image of the sun .787 inches in diameter is formed on the slit of the spectograph inside the building.

The 4 inch diameter, 13.5 foot focal length lens is installed at the top of the tower just beneath the platform. This complements the 6 foot focal length lens, which is used for daily records of calcium flocculi and prominences.

Parallel with the tower and inside the building, the spectrograph is located. This consists of a light-free, plywood box, 15 x 30 x 5.5 inches with a removable cover. The optics in the spectrograph are arranged so that the sun's light passes first through the first slit, which is adjusted to a width of .003 inches. Then it goes through the 396 cm. focal length lens, is dispersed by the two 45° prisms, reflected by the plane mirror back to

the other lens, and is focused on the second slit, which is set on the K line of calcium in the near ultraviolet. When a spectrogram is taken, the second slit is removed, and the spectrum is focused on the photographic plate. When a photograph of the sun is taken showing it as in white light, the plane mirror is adjusted so that part of the continuous spectrum passes through the second slit instead of an absorption line. This is done, rather than putting the film in place of the first slit, in order to avoid the chromatic aberration caused by the use of non-achromatic lenses.

The most important part of this project to me is the program of research for the instrument.

1. Spectoheliograms of the sun's disk, showing calcium flocculi, using the 6 foot focal length lens; to be taken daily, weather permitting.
2. Spectroheliograms of exceptionally active areas of the sun's disk, using the 13.5 foot focal length lens, which will give a larger image; to be taken when the above indicates the desirability of finer detail.
3. Spectroheliograms of calcium prominences; to be taken directly after project 1. A metallic screen will be used to cover the sun's disk. The six foot focal length lens will be used.
4. Spectroheliograms of large and unusual prominences when project 3 indicates desirability. The 13.5 foot focal length lens will be used.
5. Photographs of spots and floculae taken with continuous spectrum on second slit; to be taken at the same time that projects 1 and 3 are undertaken.
6. Spectrograms of bright stars just before occultation by the moon to help determine the existence of a lunar atmosphere.
7. Spectrograms of all first and second magnitude stars that are within the latitude range of the instrument.
8. Spectrograms of the five bright planets.
9. Photographs of the moon, planets, stars, clusters, and nebulae in white light, using the telescopic mirror and a lensless camera.

➤ HOW THE *Tesla Coil lights fluorescent tubes by induction was demonstrated in the Second National Science Fair, 1951 by Jim Arden Gilbreath of Chanute Senior High School, Chanute, Kansas.*

The Tesla Coil

Gilbert Edwin Gowen: Construction and Testing of High-Frequency Transformers, or Tesla Coils. St. Monica's High School, Santa Monica, Calif. Honorable Mention, 12th S.T.S., 1953.

➤ THE TESLA COIL, or high-frequency transformer, was invented by the famous Serbian electrician, Nikola Tesla, in the latter part of the nineteenth century during his experiments with high-voltage high-frequency currents. But high-frequency transformers and phenomena were only a part of his whole field of investigation. Tesla set up his own electrical laboratories

in New York City, and the resulting inventions have been distinguished for their brilliance as well as for their practicability. He was the first to substitute A.C. for D.C.—by devising a simpler generating method than previously known. His principle of the rotating magnetic field is now widely used in all A.C. electrical equipment. Tesla's other inventions were along lines of arc and incandescent lamps, condensers, radio apparatus, and high-frequency transformers, otherwise called Tesla Coils, which I will discuss here.

The coil I have experimented with is a form of the Tesla Coil developed by Oudin, who pirated the original theories and plans from Nikola Tesla. The Oudin circuit, as it was called, differs from Tesla's coil in that it has a small secondary coil placed between the primary and the helix coils.

The first step in the construction of my coil was the making of the primary, secondary, and helix coils. First, I obtained a cardboard tube 3 feet long and 4 inches in diameter, shellacked it inside and out, and dried it in a hot place to drive out all the moisture. Next I wound many turns of fine wire around the tube, leaving ¼ of an inch on each side free, and then painted over the wire with a special voltage resistance lacquer. Then I fixed the tube on a sheet of wood, 2 feet square, and then plugged the top of the tube with a cone-shaped piece of wood upon which I had placed a metal knob. This finishes the primary coil except to connect the coil to the metal knob and secondary coil. The secondary coil is about 10 turns of wire wound around the base of the primary, at least 5 inches away to prevent sparking between it and the primary. The helix is a more difficult coil to construct. It is made by drilling holes in the base of the primary, and gluing 3 pairs of hardwood cleats in an upright position. The helix is completed by winding 9 complete turns of bare copper wire around the cleats, hooking it up with the secondary, and then clamping on two leads; one to go to the condenser, and one to go to the interrupter.

The next step in the construction is the condenser. I made my condenser out of a war surplus gas tank, plate glass, and aluminum foil. First I cut the top of the tank, and shaped the glass plates, 28 of them, to fit into the tank, one on top of another. Next I cut the aluminum foil in sheets slightly smaller than the glass plates, and rounded off the corners to reduce the corona. The foil was then placed between the glass plates and sealed upon them by paraffin. Now I placed the glass plates in a stack so that tabs of the foil protrude out between the plates alternately, one on each. The pile of plates and foil can now be strengthened with friction tape and light twine, and placed into the tank. The tabs of the foil can now be connected with wire so that there are two leads to the condenser; one to go to the transformer, the other to go to the helix. Finally, the condenser is finished by filling the tank with transformer oil, to insulate the condenser.

The final step in the construction of my coil is the interrupter. The interrupter I devised is motor driven, a small electric motor giving the needed power. The base of my interrupter is a metal plate, set upon wooden blocks. The motor turns a dielectric plastic

rod which in turn turns a metal disk which has been cut into a star shape with nine points. The rod is stabilized by running it through a one inch thick board of fibreboard on each side of the disk. Two standoff resisters complete the interrupter, one on each side of the disk, with leads attached to them; one lead goes to the transformer, the other is attached to the helix.

The final part of my Tesla Coil is the transformer, a part which I did not construct. For the testing of the coil I used an oil transformer, of the type used on power transmission lines. I switched the leads of the transformer so that I was able to obtain 15,000 volts at 15 milliamps from the ordinary household circuit. I also attached 3 porcelain resisters to the positive lead of the transformer to prevent blowing a fuse on the household current.

I carried out the testing of the Tesla Coil in a darkened room so that I could find any leakage of the condenser and the coil by watching for the corona, and so that I could observe better the spectacular effects of the coil in operation. In my coil, the discharge points are the metal knob on the top of the primary coil and another knob on a dielectric rod held in my hand. This would not be dangerous even though they could conduct, because at frequencies of 25,000 cycles and above, the current only travels on the outside of the conducting body.

The first test I conducted with the coil was to measure the intensity of the spark at increasing distances. I noted that the discharge varies in type and intensity with increasing distance between discharge points. After stretching the discharge points beyond the breakdown limit, I noted how a corona formed around the discharge point on the top of the coil. I examined the corona region for evidence of the breakdown of the oxygen in the air to nascent oxygen and ozone by drawing air from the area into my lungs through a straw and noting the exhilarating effect of the ozone. Then I hooked up 1 and 2 inch hoops of fine wire to the knob on the top of the coil and noted that no corona will form within the circle of wire. This effect is the one studied by the great scientist, Michael Faraday, who also made many studies along the lines later followed by Tesla. Next, I cut out a tin star with a hole in the center, and then fitted it over the discharge point on the coil. When the power is turned on, the corona will form around the edges and points in a more intense discharge than that at the center. Then I hung a fine-wire pattern on the discharge knob, and noted the corona effect which greatly resembles the Northern Lights.

Testing For Resonance

Philip Williams: Making a Tesla Coil. Olympia High School Olympia, Wash. Honorable Mention, 13th S.T.S., 1954.

➤ THE TESLA COIL is simply a form of transformer. This transformer consists of a secondary coil containing many turns and a primary coil having only a few turns in relation to the secondary. Both coils have an air core and the secondary is usually placed inside the primary. A high frequency

current, introduced in the primary coil, is induced into the secondary coil, which, because of its many turns in relation to the primary, produces an increase in voltage. This high voltage shoots electricity off in all directions from the discharge ball at the top end of the secondary. Although the voltage produced is high one will not get shocked, only burned, by the output of a Tesla coil as the electricity is of sufficiently high frequency to skim over the surface of the skin instead of penetrating into the body.

The oscillator used to produce the oscillations in the primary coil is usually one of two types, vacuum tube, or spark gap. A vacuum tube oscillator, while giving more stable operation, is harder to obtain parts for than the spark gap oscillator, therefore, I used the spark gap oscillator. This oscillatory circuit uses a spark gap, condenser, coil, and high voltage power supply.

When voltage is applied to the primary circuit the condenser begins charging. When the charge on the condenser reaches a high enough voltage a spark discharges across the spark gap thus lowering the resistance of the circuit and permitting the electrons to oscillate through the circuit from one condenser plate to the other. The frequency of such a circuit, like the tuning circuit of a broadcast receiver, depends mainly on the size of the inductance and capacitance.

I obtained about two pounds of number 26 single cotton covered wire and a mailing tube about four inches in diameter and a yard long. To make the secondary I shellacked the mailing tube, wound all the wire on it starting about two centimeters from one end, and cut off the excess tubing about three centimeters from the top of the winding. I shellacked the coil again and added an inverted plastic funnel to the top to mount the discharge ball on. I made the primary coil by winding sixteen turns of number 16 strand antenna wire on a shellacked oatmeal container spacing the turns about one centimeter apart. I mounted these coils on a wooden base. The spark gap for the oscillator was made by mounting two binding posts on wooden blocks and gluing these blocks to the base. The binding posts permitted adjustment of the spark gap. I used two copper nails to form the gap itself.

To operate this kind of Tesla coil requires a condenser and a high voltage supply. For my condenser I used window glass cut to a size of 7 x 5 inches. I sandwiched aluminum foil between the glass plates and brought the leads from adjacent plates out opposite sides. I mounted the condenser in a cigar box I prepared by bolting aluminum foil strips to opposite sides of the box and attaching Fahnstock clips to the ends of the bolts. When the condenser was slipped into the box the tabs on the aluminum foil plates made contact with the strips on the sides of the box, thus permitting the number of plates in the condenser to be varied easily.

For the high voltage supply I went to one of the local neon sign companies and obtained a neon light transformer that delivers five thousand volts. I mounted this in a box and provided it with a power cord, off-on switch, and two terminals for the high voltage outlet.

As the best possible performance from a Tesla coil is obtained when

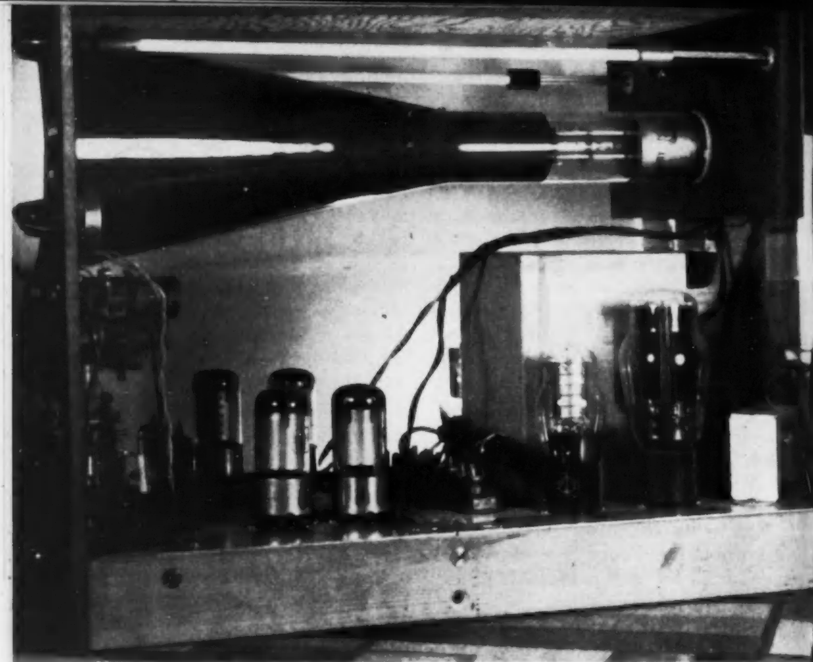
the primary and secondary circuits are in resonance, I set out to find the conditions under which this could best be achieved. Upon running the coil for the first time I found that sparks would jump between the primary and secondary windings due to the close coupling between them. I remedied this situation by making a shield out of parafin blocks which I could slip between the primary and secondary coils.

The first thing I studied was the effect on the high frequency output of a variation in capacitance. I set the inductance clip on the next to the top turn and set the spark gap in the oscillatory circuit at about one millimeter. I then started out with six plates in the condenser and increased the size of the condenser by two plates until I reached a total of thirty plates. The high frequency spark distance measured was the greatest distance which a spark would jump across continuously. The final results of this study showed that the increase in spark length corresponded to the increase in capacitance until an average of 26 plates was reached, then the addition of more plates only shortened the length of the final spark. A condenser containing 24 plates was found to be most reliable.

The next test involved the oscillator spark gap. I increased the length of the spark by one millimeter each time until it reached a distance of five millimeters, which I found to be the longest reliable distance. The results showed that the output increased until an average distance of about two millimeters was reached and then decreased to a low at five millimeters A possible explanation for this distribution may be that at the closer distance, when the resistance is less, the voltage will become high enough to overcome the resistance of the gap before the condenser charges to full voltage, while at the greater distances the charge on the condenser will drop below the necessary voltage to jump the gap in too short a time, thus giving a shorter period of oscillations per condenser charge.

With the results of the two preceeding tests in mind I started to measure the effects of varying the primary inductance. A decrease in the number of turns in the coil would increase the frequency of the circuit. By changing the number of turns in the coil I could tune the circuit to closer resonance with the secondary circuit. I found that in general the length of the high frequency spark increased as the inductance became greater, with the longest spark produced with a fourteen turn coil. However, as the number of turns increased the overall operating dependability decreased, thus the aparatus worked smoother with a small inductance than with a large one.

As a result of these tests I learned the value of achieving a fair degree of resonance between the primary and secondary circuits and I learned something about how to obtain resonance. With these factors in mind I hope to be able to build another Tesla coil that will operate with greater efficiency.



➤ HOME-MADE *oscilloscope constructed by Byron Elbert Blanchard. Each section of the assembly is mounted on a separate base, so that one part after another can be removed for individual experiments. On the following page begins his account of how he built the instrument.*

The Oscilloscope

➤ THE OSCILLOSCOPE, a handy device for checking radio and other electronic circuits, has as its heart a cathode ray tube. Electrons boiled off the cathode of this tube are shot at its phosphor-coated screen, causing a spot to appear.

The beam of electrons can be directed from side to side and from bottom to top by applying voltages and wave forms to the appropriate deflection plates in the neck of the tube. Thus it is possible to show sound waves when a telephone transmitter is connected to the "vertical deflection" input.

By applying standard "sweep" frequencies to the deflection plates, and by modulating the intensity of the electron beam, engineers have created television.

In the following reports, young electronics enthusiasts tell how they built and used their oscilloscopes.

Making the Instrument

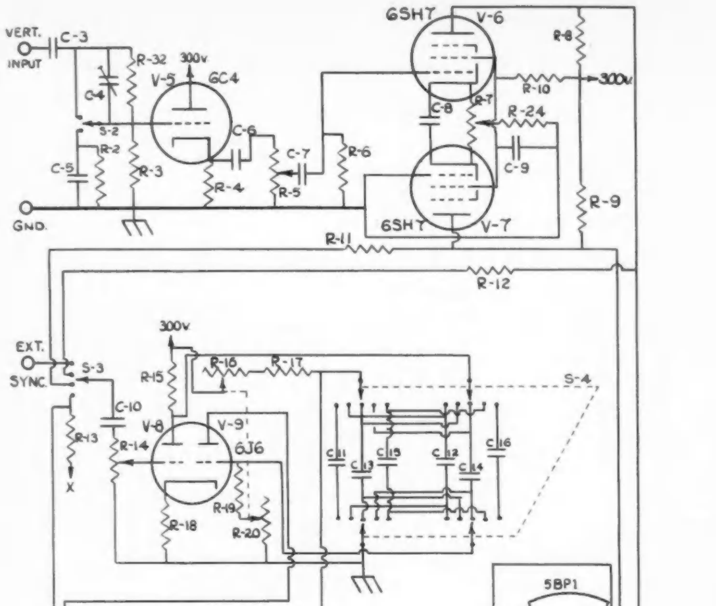
Byron Elbert Blanchard: Cathode-ray Oscilloscope. Central High School, Omaha, Nebr. Winner, 11th S.T.S., 1952.

➤ A CATHODE-RAY oscilloscope is a device which can portray electronic phenomena, involving voltage and current, visually, and is the most versatile of electronic measuring devices. For a long time before the oscilloscope was offered to the maintenance branch of the radio industry, it was seen only in best equipped laboratories of electric equipment manufacturers. Today, however, its usefulness as a measuring and designing instrument capable of doing a better job than other types of test equipment in countless fields of electronics is appreciated.

Considering the rapid strides made recently in the field of electronics and oscillography and the likelihood that the oscilloscope's importance will increase in the future, I concluded that the cathode-ray oscilloscope would be a subject worthy of study by a student of science. I examined many complete oscilloscopes and kits available commercially in order to find the best and worst features of each, before I decided to design and construct a home-made oscilloscope which would combine what I thought were the best features of those examined.

In the construction of my oscilloscope, the choice and type of cathode-ray tube was governed by availability and cost. I chose the 5BP1 tube because it could be purchased on the surplus market for twenty-five cents and because its size was convenient for demonstration work. The general construction, I believe, is unique in that the oscilloscope is built on aluminum plates fastened to a wooden frame. The vertical amplifier, sweep generator, horizontal amplifier, and power supply are each on an individual plate to facilitate removal of one part for experimentation without disturbing the other parts of the instrument. This feature has been very useful in that it allowed me to remove the power supply from the oscilloscope proper for the reasons set forth below. For the purpose of explanation in this paper, I will divide the units comprising my oscilloscope in the same manner and order that I did when designing it. These four units are the power supply, the vertical amplifier, the sweep generator, and the horizontal amplifier.

First, I designed the power supply to furnish 2,000 volts direct-current for the cathode-ray tube, plus plate and filament voltages for the other stages. The only power transformer available with 2,000 volt secondary was a shielded upright-mounted one with a 350 volt at 160 milliampere secondary in addition to the 2,000 volt secondary, but with no filament windings. The completed supply uses three filament transformers in addition to the high voltage transformer. The power supply is capable of powering accessories which I hope to add later, such as an electronic switch or audio-signal generator. I was not sure how sensitive the cathode-ray tube was to external magnetic fields although I had read that certain precautions should be taken; so, I went ahead and built the power supply in



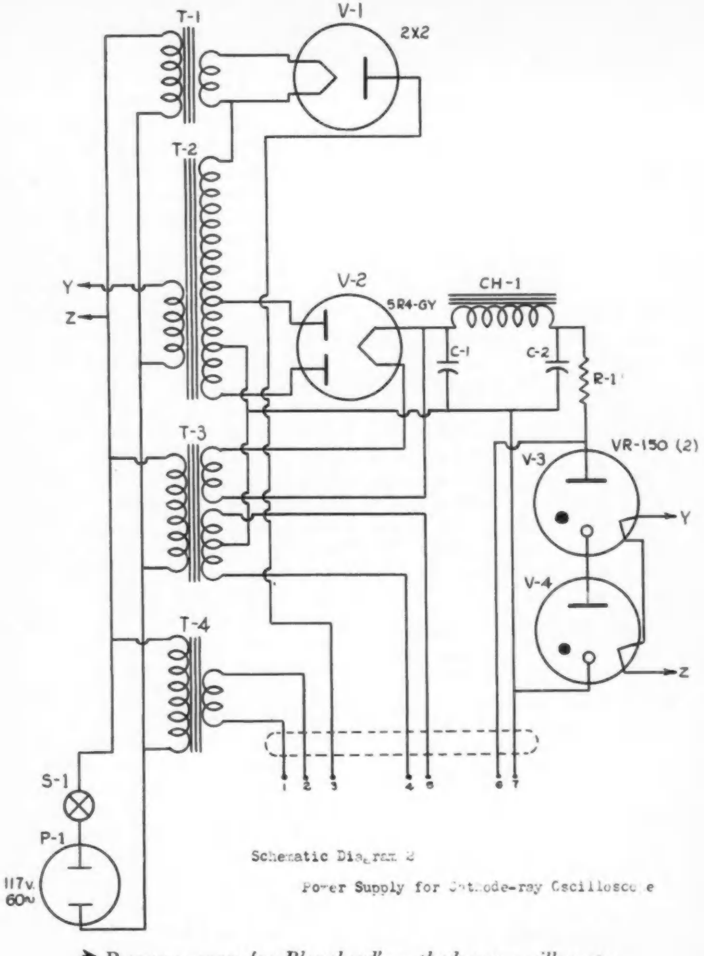
Schematic Diagram 1

Cathode-ray Oscilloscope

➤ Cathode-ray *oscilloscope as built by Blanchard.*

the same cabinet as the rest of the scope, for testing purposes. The alternating-current magnetic field from the power transformers was sufficient to deflect the spot into an oval pattern approximately one-fourth inch high. As a means of combatting this deflection which made the oscilloscope useless for most accurate observations, I made a shield first of tin cans and finally of sixteen-gauge sheet iron. Neither shield gave any substantial reduction in the deflection. The sheet iron shield was magnetized so much that even with the positioning controls at their limits the spot could not be centered. Finally, the deflection was combatted by my removing the power supply bodily from the rest of the oscilloscope, installing it on a separate frame, and connecting it to the rest of the oscilloscope with a multiconductor cable. The output of the power supply is regulated by two VR-150 voltage regulator tubes in series to give 300 volts.

The vertical amplifier is one of the most important parts of the oscilloscope. In almost all measurements, the signal to be observed must pass through the amplifier, and, for minimum satisfactory square wave response, the amplifier must pass at least ten odd harmonics of the fundamental frequency. Some of the most important considerations in design are frequency response, gain, and amount of distortion. One of the ways of broadening the response is to insert peaking inductances in the circuit. Since these inductances are rather critical in adjustment, it is impractical to make them one's self. These inductances are not available locally; and, since they cost approximately nine dollars each, I designed an amplifier which would have the best frequency response obtainable without inductive peaking. I decided on push-pull deflection because it gives the most linear trace, since a balanced condition then exists between the deflection plates and the accelerating electrode. Cathode coupling gives the needed phase inversion between the push-pull stages. Directly coupling the plates of the amplifier to the deflection plates of the cathode-ray tube eliminates the phase shift that might occur if coupling capacitors were used. The positioning control is placed in the cathode circuit of the 6SH7's where it varies the grid bias on each tube, changing the plate current. When the plate current changes, the voltage drop across the plate resistor changes; this change is coupled to the deflection plates of the cathode-ray tube, moving the spot. To attain useful attenuation without adversely affecting the frequency response, I used a cathode-follower stage feeding into a low resistance potentiometer connected to the input of the push-pull stages. The gain of a cathode-follower is approximately unity; it acts only as an impedance transformer so the continuously variable gain control can be placed in a low impedance circuit. To keep the input of the cathode-follower from being overloaded on strong input signals, I put in a frequency compensated step attenuator consisting of C-4, R-32, C-5, and R-2. In the testing I have done so far, the frequency response seems satisfactory, but the amplifier is overloaded and distorts the trace when the trace is expanded almost to the full size of the screen. I have not worked out this



➤ POWER SUPPLY *for Blanchard's cathode-ray oscilloscope.*

problem as yet; but I will probably try to use lower mu tubes in place of the 6SH7 tubes.

The sweep circuit, or time base generator, is a cathode-coupled asymmetrical multivibrator using a 6J6

dual triode in a rather conventional circuit. The sawtooth frequency is variable in five ranges from approximately fifteen cycles to seventy-five kilocycles per second. The triode V-9 is cut off during the charging of the capacitor from its plate to ground; but, when the RC network connecting the plate of V-8 to the grid of V-9 loses its charge, V-9 momentarily passes a very large current in discharging the aforementioned capacitor. As the voltage across the condenser rises gradually and then drops rapidly, a sawtooth wave is formed. In the middle and upper portions of its frequency range, the sawtooth is very linear; but in the lowest portion of its range, the capacitor from plate to ground of V-9 is not large enough. As a consequence, the voltage swing occurs over the more rounded part of the charging voltage curve. The multivibrator can be synchronized to an external voltage, the signal applied to the vertical deflecting plates or to the sixty cycle line voltage.

The horizontal amplifier does not need to have as wide a frequency response as the vertical amplifier since it will usually have to pass only a sawtooth wave. The frequency response required by a sawtooth wave is substantially less than that for other complex waves; while a square wave requires approximately ten *odd* harmonics, the sawtooth wave requires only about ten harmonics, both even and odd. Because of the reduced frequency requirement, the cathode-follower and step attenuator are left out. The push-pull amplifier and positioning control are the same as in the vertical amplifier, while the gain control is a potentiometer placed in the input circuit. The input selector switch S-5 enables the user to select either the sweep generator, sixty cycle line voltage, or some external input. The switch turns off the sweep generator when it is not being used to prevent any stray coupling into the horizontal amplifier or the other parts of the oscilloscope.

The applications of the oscilloscope are limitless. Any electrical impulse, wave, or current, or anything to do with any electronic equipment, from hearing aids to induction heaters, can be observed, measured, or compared with any other signal. With the use of a transducer to convert any mechanical or other nonelectrical phenomena into electricity, the oscilloscope can investigate all physical quantities. Because of the universal application of the oscilloscope in science, industry, medicine, and education, it is important that the young scientist comprehend its theory and applications to the measurement and graphical presentation of phenomena encountered in the study of light, heat, pressure, sound, magnetism, etc. The designing and construction of my own oscilloscope has, I feel, given me at least a foundation for the comprehension of the applications and possibilities of the cathode-ray oscilloscope.

Parts List for Cathode-Ray Oscilloscope

RESISTORS

R-1	8000 ohm 20 watt wire-wound
R-2	33,000 ohm ½ watt
R-3	3.3 megohm ½ watt
R-4	3300 ohm ½ watt
R-5	5000 ohm wire-wound control vert. gain
R-6	0.68 megohm ½ watt

R-7	300 ohm wire-wound control vert. center
R-8	0.22 megohm ½ watt
R-9	0.22 megohm ½ watt
R-10	0.39 megohm ½watt
R-11	3.3 megohm ½ watt
R-12	3.3 megohm ½ watt
R-13	10,000 ohm ½ watt
R-14	0.1 megohm control sync. amplitude
R-15	47,000 ohm ½ watt
R-16	1 megohm control ganged with R-20 freq. fine
R-17	47,000 ohm 1 watt
R-18	470 ohm 1 watt
R-19	27,000 ohm ½ watt
R-20	0.25 megohm control ganged with R-16
R-21	0.25 megohm control hor. gain
R-22	300 ohm wire-wound control hor. center
R-23	470 ohm 1 watt
R-24	470 ohm 1 watt
R-25	0.22 megohm ½ watt
R-26	0.39 megohm ½ watt
R-27	0.22 megohm ½ watt
R-28	1 megohm 2 watt
R-29	0.5 megohm control focus
R-30	0.27 megohm 1 watt
R-31	0.1 megohm control intersity
R-32	3.3 megohm ½ watt

CAPACITORS

C-1	5mfd. 600 volt oil
C-2	16 mfd. 600 volt electrolytic
C-3	.25 mfd. 600 volt paper
C-4	3-30 mmfd. mica trimmer
C-5	680 mmfd 500 volt ceramic
C-6	10 mfd. 25 volt electrolytic
C-7	.1 mfd. 600 volt paper
C-8	.02 mfd. 600 volt paper
C-9	8 mfd. 450 volt electrolytic
C-10	.01 mfd. 600 volt paper
C-11	.5 mfd. 400 volt paper
C-12	.1 mfd. 400 volt paper
C-13	.02 mfd. 600 volt paper
C-14	.003 mfd. 600 volt paper
C-15	500 mmfd. 500 volt ceramic
C-16	82 mmfd. 500 volt ceramic
C-17	.25 mfd. 400 volt paper
C-18	.02 mfd. 600 volt paper
C-19	8 mfd. 450 volt electrolytic
C-20	.25 mfd. 2000 volt oil

SWITCHES

S-1	SPST toggle switch A.C. on-off
S-2	SPDT rotary switch vert. input attenuator
S-3	SP4T rotary switch sync. selector
S-4	4P5T rotary switch coarse freq.
S-5	DP3T rotary switch hor. input selector

TRANSFORMERS

T-1	Primary 117 volts 60 cycles, secondary 2.5 volts 5 amperes (Stancor P-6133)
T-2	Primary 117 volts 60 cycles, secondary 1500 volts 2 milliamperes, 700 volts 160 milliamperes (Thordarson 651019)
T-3	Primary 117 volts 60 cycles, secondary 5 volts 2 amperes and 6.3 volts center-tapped 4 amperes (Special)
T-4	Primary 117 volts 60 cycles, secondary 6.3 volts 1.2 amperes (Stancor P-6134)
CH-1	8 henry 150 milliampere filter choke

PLUGS

P-1	A.C. power plug

Use of the Oscilloscope

John Charles Reynolds: Use of the Cathode-Ray Oscilloscope in Acoustical Demonstrations. Glenbard Township High School, Glen Ellyn, Ill. Winner 12th S.T.S., 1953.

➤ THE ABILITY of a cathode-ray oscilloscope to display and measure wave forms and other periodic functions over a wide range of frequencies makes it an extremely useful instrument for the demonstration and analysis of sound waves. In this project I have endeavored to show four uses of an oscilloscope in the study of sound and acoustics. The oscilloscope used was a Du Mont Type 274-A Cathode-ray Oscillograph, with a five-inch screen. The time base generator produces a sawtooth wave with a frequency of from 8 to 30,000 cycles per second, which can be synchronized with the vertical input.

The sounds produced by musical instruments contain, in addition to the basic or fundamental tone which determines the pitch, a number of tones of multiple frequency, called overtones or harmonics, whose relative intensities determine the "timbre" or tonal color of the instrument. The sound wave emitted represents the sum of the component fundamental and overtones, and is called a complex wave.

The cathode-ray oscilloscope can be used to show the patterns of complex waves simply by connecting a microphone to the vertical input and applying a synchronized sawtooth wave to the horizontal input. However, in view of the time consumed in photographing the wave forms, I found it more convenient to use tape recordings of the various tones.

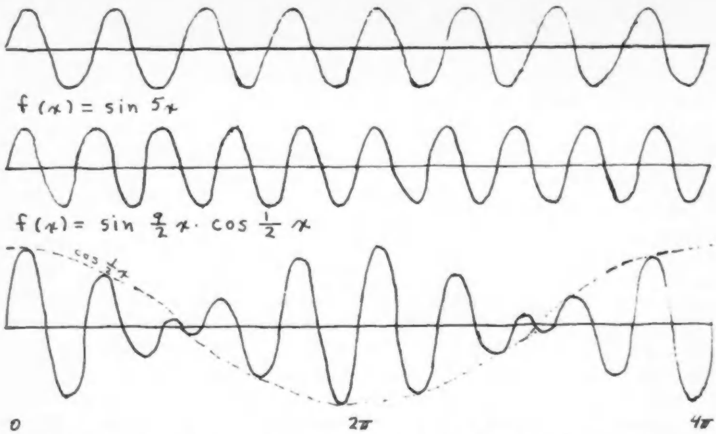
Recordings were made of the following wind instruments: flute, oboe, clarinet, bassoon, trumpet, and French horn. Each player played all of the concert "A's" (880, 440, 220, 110 cycles) conveniently within his range.

The recordings were then played into the oscilloscope. With some instruments there was an objectionable amount of image wavering due to vibrato and background noise. In these cases I reduced the wavering somewhat by feeding the signal from the tape recorder to a loudspeaker and picking up the sound with a microphone attached to the vertical input.

If two sound waves of nearly equal frequencies are heard simultaneously, a pulsating effect, called "beating," is noticed. This is due to the reinforcement of the two waves when in phase and the cancellation when out of phase. The frequency of these "beats" is equal to the difference between the frequencies of the two interfering sounds.

Using two audio oscillators connected in parallel to the vertical input of the oscilloscope, I was able to produce patterns showing this reinforcement and cancellation of waves. In order to produce a steady, observable pattern on the oscilloscope, the beat frequency must, in general, be too high to be heard as distinct beats or pulses. This makes it difficult to demonstrate the beats audibly and visually at the same time.

If both the horizontal and vertical inputs of an oscilloscope are connected



➤ CONSTRUCTION *of beat waves by combinations of different waves.*

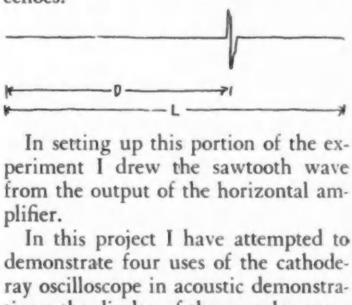
to sources of sine waves, a curve called a Lissajous (or Bowditch) figure will be produced. The shape of the curve will depend upon the ratio of the frequencies of the sine waves and their phase angle.

When the frequencies are equal, the resulting figure will be a diagonal line, an ellipse, or a circle, depending upon the phase angle.

When the frequencies are in the ratio of small whole numbers, more complex Lissajous figures result.

If the sawtooth wave produced by the time base generator of the oscilloscope is amplified and passed through a loudspeaker, a series of loud, sharp sound pulses or "clicks" will be produced. If a microphone is then connected to the vertical input these clicks will create sharp vertical deflections on the oscilloscope image.

The duration of time necessary for the impulse to travel from loudspeaker to microphone is equal to the relative distance "D/L" divided by the frequency of the sawtooth wave. This provides a method of determining approximately the velocity of sound, and measuring the reverberation time of echoes.



In setting up this portion of the experiment I drew the sawtooth wave from the output of the horizontal amplifier.

In this project I have attempted to demonstrate four uses of the cathode-ray oscilloscope in acoustic demonstrations; the display of the complex wave forms of musical tones, the demonstration of "beat" patterns occurring when two tones of slightly different frequencies are heard simultaneously, the use of Lissajous figures to determine the frequency and phase relationships of

two sine waves, and the timing of sound pulse propagation to determine the velocity of sound and to measure echoes.

These are only a few of the many possible uses of this versatile instrument in the study of sound. It should be of great practical use to both scientists and musicians in the study and demonstration of intonation, vibrato and tremulo, complex waves, frequency relationships, echoes and reverberation, and other acoustic phenomena.

The mathematical analogy of the beat pattern is the addition of two sine functions of different periods. The equation of the beat pattern is therefore:

$$f(x) = \sin ax + \sin bx$$

where a and b are the frequencies of the two interfering waves. According to the laws of trigonometry, this function may be rewritten:

$$f(x) = \sin \frac{a+b}{2} x \cdot \cos \frac{a-b}{2} x$$

The factor $\sin \frac{a+b}{2} x$ gives the basic frequency of the wave, namely the arithmetic mean of the two frequencies, while the factor $\cos \frac{a-b}{2} x$ controls the "beat"; that is, as the cosine approaches one or minus one the sound intensity approaches its maximum, as the cosine approaches zero the intensity approaches zero. It can easily be seen that there are two maximum intensity points for each period of the cosine function. Therefore, the beat frequency is twice the frequency of the cosine function, in other words, equal to $a - b$.

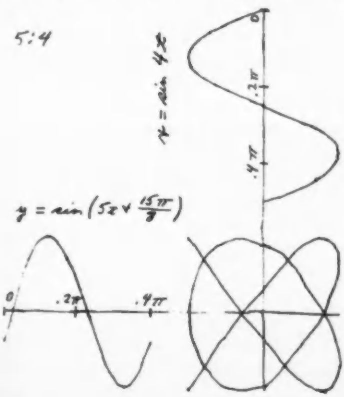
The graph below shows the formation of the beat pattern:

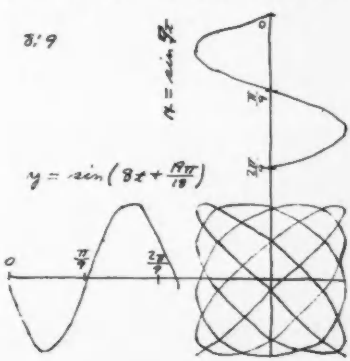
$$f(x) = \sin 4x + \sin 5x = \sin \frac{9}{2} x \cdot \cos \frac{1}{2} x$$

Lissajous figures are defined by the general parametric equations:

$$x = \sin at : y = \sin (bt + \phi)$$

It will be seen that each of these equations defines a sine curve. Thus a Lissajous figure may be constructed by taking as abscissa and ordinate the values of x and y on the sine curves which correspond to equal values of t.





Lissajous Figures

Michael Peter Grant: A Study of Lissajous Figures. Oshkosh High School, Oshkosh, Wis. Winner, 12th S.T.S., 1953.

➤ LISSAJOUS Figures are patterns formed by two vibrations moving at right angles to each other. They show the relationship between two frequencies.

Figures of this type were first studied in a limited way by Nathaniel Bowditch of Salem, Massachusetts, in 1815. From his work these patterns are sometimes known as Bowditch Curves. The first really comprehensive study of these figures was made by Jules Antoine Lissajous of Paris, who presented a paper on this subject to the Paris Academy of Sciences in 1857.

There are a number of methods of producing Lissajous Figures. Several will be covered in this paper.

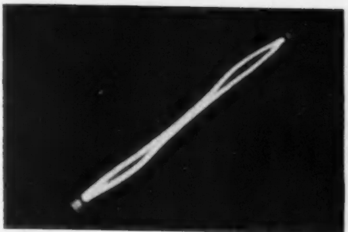
The most convenient way, if the proper equipment is available, is with a cathode ray oscilloscope and a signal generator. A 60 cycle tone from the power lines may be used to drive one of the axes of the oscilloscope. The signal generator is connected to the other. The resultant curve will depend on the multiple of 60 being generated by the signal generator and on the phase difference of the two tones. With this equipment an infinite number of patterns may be produced by a variation of the frequency selector of the signal generator. The figures produced on the oscilloscope adapt themselves to being photographed by any camera having a fairly fast lens using high speed panchromatic film.

The first apparatus I used to produce these figures mechanically consisted of two pendulums with their bearings arranged so they swung at right angles. The bearings were mounted about three-quarters of the way from the bob of each pendulum. At the top of each pendulum were mounted a set of brackets. One held a small table, the other a long arm which reached to the table. This arm held a pen, which drew on a paper on the table. As the pendulums could be varied in length, many combinations were possible. Much experimentation was conducted with this apparatus and many satisfactory patterns drawn.

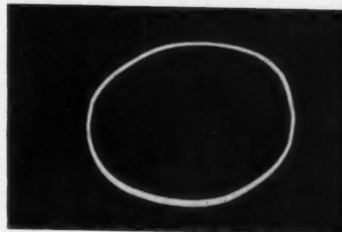
Lissajous Figures may also be produced with an apparatus known as a sand pendulum. A hollow bob filled with sand is suspended from a double cord. This cord is fastened to two points. Partway down the cord is mounted a heavy sleeve which brings the cords together. The upper part is set swinging in one direction, while the lower part swings independently at right ang'es to it. The ratio of the periods of the pendulum may be varied by changing the position of the sleeve. This method, however, requires a considerable amount of experimentation to produce a desired pattern. The motion is quite highly damped so that the figure often is not too clearly defined.

Another method that was tried is to mount a rectangular rod, which has been bent at right angles, firmly at one end. At the other end is fastened a white ball or a dot of white paint. By pulling the ball to one side and releas-

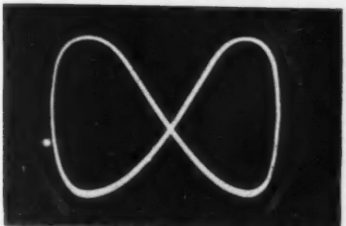
Lissajous Patterns in the Oscilloscope



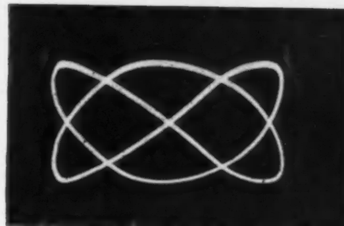
➤ SIGNALS *in 1:1 ratio, in phase.*



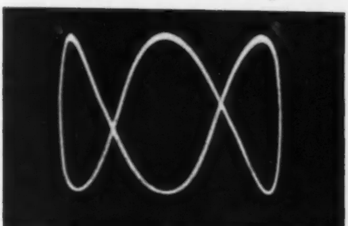
➤ SIGNALS *1:1 ratio, 45° out of phase.*



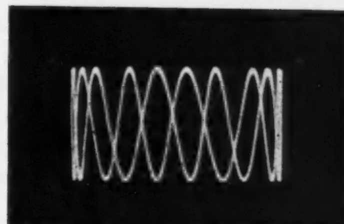
➤ SIGNALS *in 2:1 ratio, in phase.*



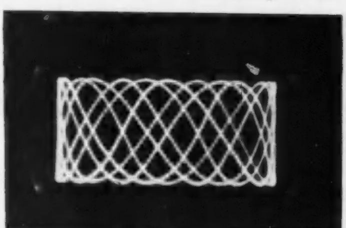
➤ SIGNALS *in 3:2 ratio, in phase.*



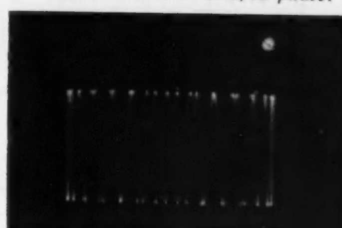
➤ SIGNALS *in 3:1 ratio, in phase.*



➤ SIGNALS *in 10:1 ratio, in phase.*



➤ COMPLEX *figure, signals 14:3 ratio.*



➤ SIGNALS *in 20:1 ratio.*

ing it, a combination of two directional movements will result. The ratio of one portion of the rod to the other determines the figure produced. As can be seen, this method is rather inconvenient in the study of many types of patterns.

This same method may be varied slightly, with the bar not being bent for this experiment. The straight bar is simply fastened tightly at one end and set in motion. In this variation the ratio of the width of the bar to its height determines the pattern produced.

The method used by both Bowditch and Lissajous in their experiments was as follows:

Mirrors are mounted on the prongs of two tuning forks. A strong light is focused upon the mirror of one fork, which reflects it into the mirror of the other fork. From this mirror the beam of light is transmitted to a screen on which the figure is viewed.

The figure corresponds to the ratios of the periods of the tuning forks used. The amplitude of the forks controls the phase changes the figure passes through.

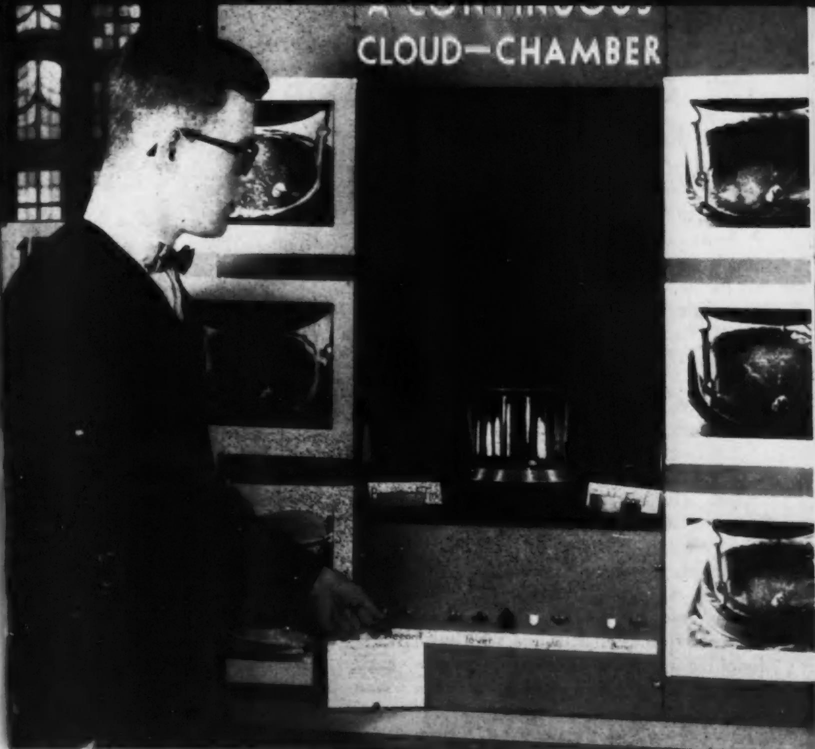
A method of producing these figures that is rather interesting is pure geometric construction. This is done on a graph paper prepared as follows:

Draw a circle on a sheet of paper. Along the circumference of this circle, lay off equal divisions. The more divisions, the more accurate the figure will be. Draw two diameters of the circle at right angles. From each division on the circumference draw the perpendiculars to the diameters. Fill the entire sheet with lines extended from the perpendiculars.

These divisions correspond to the distances a pendulum would swing if the times for each division were equal. To construct any given Lissajous Figure using this method, simply use the ratio of the frequencies of the figure desired as coordinates of the graph, assuming the x and y axes move with their point of intersection to each point graphed. Phase changes may be plotted by starting on different points of the graph rather than the left lower corner.

If we remember that in all the methods described the form of the figure produced depends on the relative speed of the two motions acting at right angles to describe the figure, we can easily see that the graph method duplicates this exactly, as the basis of the graph itself depends on relative motion of a pendulum. As the one motion moves up with its respective speed, the motion acting at right angles to it moves to the right with its given speed, theoretically independently of the other. In the oscilloscope method this is true, making this the most accurate. In the other methods the motion is more or less damped, making the figure slightly inaccurate.

In a 1:1 ratio figure, if the motions start from the lower left of the graph, the figure produced will be a straight line. However, if graphing starts from the center which is out of phase 45°, the figure will be a circle. This is explained by the fact that as the trace describing the pattern reaches the right of the graph, it starts back, as a pendulum would. It therefore continues upward and moves back toward the left. This may also be used to explain the more complicated Lissajous Figures.



➤ THE CLOUD CHAMBER *which he built forms the center of Jere DeLee Dando's exhibit in the Fifth National Science Fair, 1954. Jere is from the Shawnee-Mission High School, Merriam, Kansas. The photographs at the sides show cosmic particles he has "trapped."*

The Cloud Chamber

➤ FORMATION of tiny clouds upon ionized particles when air pressure is reduced was one of the first ways devised to see particles too small for direct vision. A more recent technique uses difference in temperature between the top and the bottom of the cloud chamber to produce the clouds.

A bit of radioactive material is usually inserted to ionize the air. Three distinct types of cloud chambers are described here.

In similar apparatus, with addition of a magnetic field, the late Dr. Robert A. Millikan measured the charge of the electron.

Cylinder and Piston Design

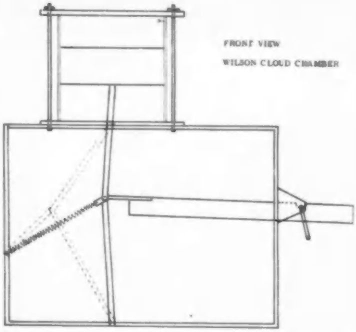
Carl Martin Rose: Construction and Use of a Wilson Cloud Chamber. Brown High School, Atlanta, Ga. Honorable Mention, 13th S.T.S., 1954.

➤ NUCLEAR PHYSICISTS would be very much handicapped in their research on the sub-atomic particles if it wasn't for a device known as the Wilson cloud chamber. Invented by C. T. R. Wilson of Cambridge in 1911, the chamber has been used to make visible tracks of particles which could not have been seen otherwise.

Although the chamber has many technical uses, it is based on two principles. They are: (1) the ionizing effect of sub-atomic particles and (2) the tendency of clouds to form when air which is saturated with water is allowed to expand rapidly. In order for a cloud to form, though, there must be some nucleus on which to form. The ions formed by charged particles supply the necessary nuclei. Therefore, when a charged particle passes through the chamber it leaves a path of tiny "clouds."

There are many designs for cloud chambers and it was necessary to choose the one which would be best suited for this project. The cylinder and piston design was chosen. The plans for this chamber were based on the principles of this particular type, i.e., a cylinder acting as the actual chamber and a piston to provide the rapid expansion of air. It was decided to use a lever system to operate the piston.

Plastic was selected as the material for the construction because of its transparentness, strength, light weight and workability.

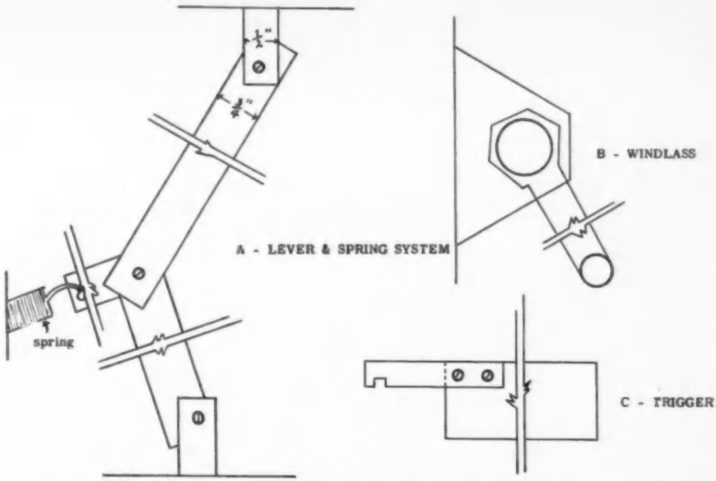


➤ THE WILSON *cloud chamber which Carl Martin Rose built is actuated by a simple spring and lever mechanism.*

The piston was made first because it was thought to be easier to fit the cylinder to the piston than vice versa. Eight pieces of $\frac{1}{4}$" "Plexiglass" were sawed into blanks and then joined together with acetone to form a rough piston, two inches high and approximately six inches in diameter. The piston was then smoothed down with a file and sandpaper. The face of the piston was painted black to make the tracks visible.

The cylinder was made of one piece of three-sixteenths inch "Plexiglass." Six inches was selected as the height of the piston and the circmference was determined by the piston. The plastic for the cyinder was heated and bent into a cylindrical shape. The ends were joined with acetone. The cylinder was heated again and formed into its final shape by pushing the piston through it until it was hard.

The mechanism for operating the piston was made from two pieces of



➤ DETAILS *of the tripping mechanism of Rose's cloud chamber expansion arrangement, and of the windlass for resetting it.*

three-fourths inch iron strips and an ordinary screen door spring. Two three inch sections of the spring were attached to the levers as shown in the drawings.

The box for the containment of the operating mechanism was made of plywood which is very strong although it is light.

The top of the chamber was made of one-fourth inch "Plexiglass" and was fastened securely by four one-fourth inch stove bolts.

Several problems were encountered in the construction. One of the most serious was that of air leaking into the chamber and preventing the formation of clouds. This was solved by fitting the top of the cylinder with a rubber gasket. A leak was also discovered between the piston and cylinder walls. Silicone high vacuum grease was used to form an airtight seal and turned out to be a very effective lubricant. Another problem was that of cocking and triggering the mechanism. The springs were too strong to be stretched by hand so a windlass system was devised and used. A trigger which would hold the lever and release it was also devised. A container for the active material and a light to illuminate the tracks were minor problems which were easily solved.

The operation of the chamber is very simple. The active material is placed in the container in the chamber. The space is then saturated with alcohol vapor by means of a piece of felt soaked in alcohol. The cover is then put on and fastened securely by the four bolts. The piston is then pushed up by the lever and windlass

and the vapor is compressed. Time is allowed for the air to become completely saturated and for the heat produced in compression to disperse. The trigger is then pulled down, releasing the spring which in turn operates the lever system. The piston drops suddenly allowing the alcohol vapor to expand and cool. Droplets of moisture then form on the ions formed by a particle passing through the chamber at the moment of expansion. A bright beam of light passing through the chamber makes the tracks visible. A camera may be placed above the chamber to record the tracks.

The only material used to date in this chamber has been a radium compound which emits alpha. Further tests will be run to determine the efficiency of the chamber with other active materials.

It is planned to make improvements on the chamber in the future. One improvement will be an electrical field which will sweep the chamber of ions after each test.

The cloud chamber has many uses in nuclear research. Since a cloud track is composed of many small cloudlets which can be considered each to have as a nucleus one ion, the strength of a particle can be found by counting the small clouds. A strong ionizing particle will have more clouds than a weaker particle in the same distance. If a strong electric field is produced horizontal to the path of the particle, then the particle will be deflected from its course. The direction and amount of deflection will depend on the electrical nature of the particle and on its mass. Therefore, an electron will be deflected toward the positive pole and will have a sharp curve of deflection because of its negative charge and its small mass. A positron will have the same degree of deflection as the electron but will be attracted to the negative pole since it has the same mass as an electron but has a positive charge. The alpha particle will be attracted to the negative pole also but will have a small degree of deflection since it has a much larger mass than the electron or the positron. The effect of the bombardment of a material with different particles can be studied from the tracks which result after such a bombardment.

Electronic Control Unit

Charles Albert Rey: Construction and Operation of a Wilson Cloud Chamber. Classen High School, Oaklahoma City, Okla. Honorable Mention, 11th S.T.S., 1952.

➤ THE CLOUD CHAMBER which I have constructed actually consists of two bakelite cylinders. One of these is eleven inches in diameter and five inches in depth, and the other is eleven inches in diameter and one inch in depth. The larger cylinder forms the expansion chamber and is placed on top of the smaller with a flexible diaphragm of rubberized fabric clamped between them.

The expansion chamber is sealed at the top by a disc of plate glass through which cloud traces may be observed or photographed. Three 100 watt incandescent lamps are spaced equally around the wall outside the chamber and illuminate its interior through small glass windows. The inner wall

and diaphragm are lined with black felt to minimize reflection.

The lower cylinder is sealed at the bottom by a metal plate to form a chamber which is connected to a vacuum tank through a solenoid operated valve. A small tube and manually operated valve also connect the vacuum tank with the upper expansion chamber. Another solenoid operated valve connects the lower chamber to outside atmospheric pressure. A motor driven vacuum pump is connected to the tank by means of a flexible hose. The complete chamber and tank assembly are mounted on an aluminum frame in such a manner as to permit tilting the cloud chamber to any angle desired. This is quite useful, particularly, for cosmic ray study.

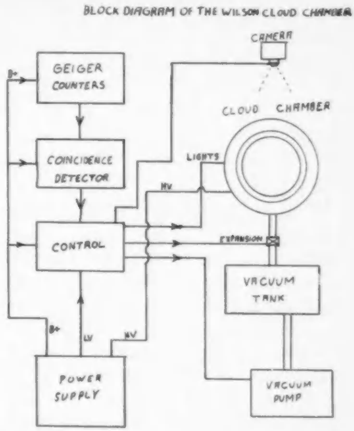
The cycle of operations for the cloud chamber is as follows:

1. The air pressure in the expansion chamber is decreased sufficiently to cause atmospheric pressure in the lower chamber to raise the diaphragm to its initial position. This adjustment need not be repeated for subsequent operations.

2. The lamps illuminating the expansion chamber are turned on.

3. When a high vacum is available in the tank, the valve to the lower chamber is operated causing very rapid reduction of the atmospheric pressure in this chamber. This causes the diaphragm to be forced downward at high speed.

4. Due to the foregoing operation, a rapid reduction of pressure occurs in the upper or expansion chamber. The air is cooled and becomes supersaturated with vapor. Cloud tracks



➤ CLOUD CHAMBER *built by Charles Albert Rey is equipped with electronic means of keeping count of the ions passing through, and a camera to photograph their tracks.*

then appear and may be observed or photographed.

5. The chamber is then returned to its normal position by opening the return valve in the lower chamber. The lights are turned off and a high D.C. voltage is applied to a small electrode in the chamber for about fifty seconds to clear the chamber of stray ions. This is called the recovery period of the chamber.

Functions of the Control Unit

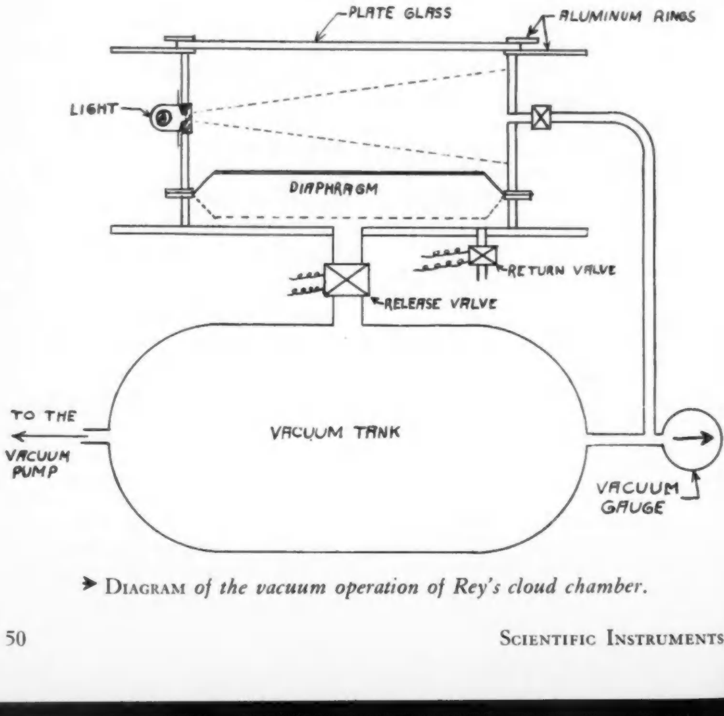
I have designed and built an electronic control unit to perform all of the above operations automatically excepting the initial adjustment. The remaining series of operations is initiated by a single push button. This control unit consists of eleven relays, eighteen switches, three power supply

units and several electronic circuits all mounted in a rack.

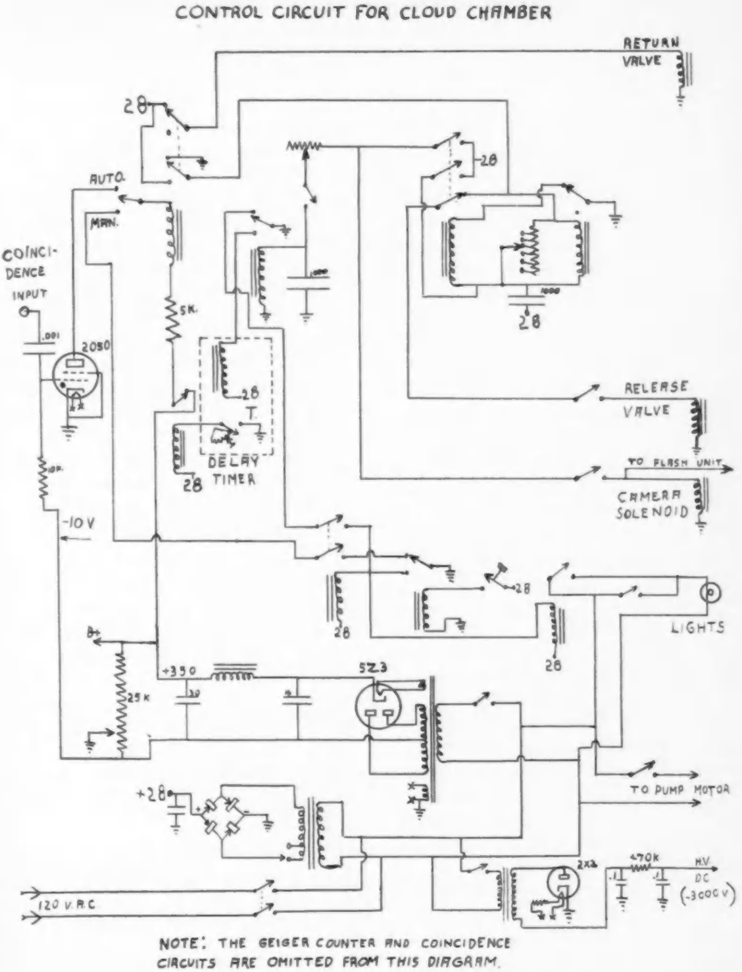
The power supply units provide twenty-eight volts D.C. for operation of the relays and solenoid valve, 350 volts D.C. for the electronic circuits and 3000 volts D.C. for de-ionizing the chamber.

Incorporated in the control unit is a timing circuit for proper synchronization of a solenoid operated camera. It also contains an electronic circuit for triggering the operating cycle of the cloud chamber from a Geiger counter coincidence detector. A Geiger counter tube is placed on each side of the chamber so that any ionizing particle passing through both tubes must also pass through the chamber. When this occurs the coincidence circuit detects the ionizing particle and produces an output pulse which triggers a thyratron tube. This in turn closes a relay which energizes the solenoid valve controlling the vacuum chamber, thus starting the cycle of operations. Another feature is a time delay circuit for preventing initiation of a new cycle of operations before the preceding cycle has been completed.

I have found the complete expansion of the chamber must take place in about .02 of a second from the time the coincidence circuit is triggered by the ionizing particle. Otherwise the trace is diffused or does not appear.



➤ Diagram *of the vacuum operation of Rey's cloud chamber.*



➤ Schematic *diagram of the cloud chamber built by Charles Albert Rey.*

Continuous Cloud Chamber

Norman W. Albright: The Continuous Cloud Chamber. Eagle Rock High School, Los Angeles, Calif. Honorable Mention, 11th S.T.S., 1952.

➤ THE CLOUD CHAMBER is one of the most important instruments for studying ionizing radiation. It operates on the principle that vapor, when supersaturated in a gas, condenses around any ions or dust particles in the gas. When ionizing radiation passes through the chamber, it leaves in its path ions, about which the vapor condenses in tracks which are characteristic of the type of radiation.

The production of supersaturated vapors in gases has been under study for 60 years. It was begun by C. T. R. Wilson, who built the first cloud chamber. The Wilson Chamber and its variations are still the chambers most commonly used today. The continuously sensitive diffusion cloud chamber is a rcent development which is not in wide use.

The Wilson chamber and the continuous chamber differ in the method by which they produce their supersaturation. A rapid and smooth volume increase in the Wilson chamber produces a near adiabatic expansion. This isentropy is better in the center than near the walls. After a few consective expansions, the dust particles and existing ions have precipitated out. Any further ions are caused by radiation present.

The top of the continuous chamber is heated causing the liquid to vaporize and saturate the gas in the chamber. When the bottom is cooled, the result is a supersaturation of the vapor in the gas. This provides a sensitive layer near the bottom of the chamber.

The Wilson chamber has moving parts which need a motor and a strong power source. Also, a trigger mechanism is needed to actuate the camera during the brief interval when the chamber is sensitive. The continuous chamber does not undergo pressure or volume changes and may be constructed lighter than the Wilson. The continuous chamber needs a wire filament to heat the top, a small power source, and a block of dry ice to cool the bottom. It is easy to see that the continuous chamber has advantages over the Wilson chamber because it is simpler in design, lighter in construction, and because it continuously produces visible tracks which are photographable for at least 1/10 of a second.

However, the continuous chamber can not be used for delayed expansions. The Wilson chamber, when triggered by two Gieger tubes, can delay its expansion for a fraction of a second. The ion-pairs can be caused to diffuse by the influence of an electrostatic field. The droplets, when formed, are resolved enough to be counted, thus determining the specific ionization.

In the construction of the Continuous chamber, the bottom and top should be metal. This is because metal transfers the heat readily. Also, the use of metal provides a means for a sweep field. This invaluable aid is made by connecting a 100 or 200 volt "B" battery to the metal top and bottom. The electrostatic field which is

set up clears the chamber quickly of dust or ions. There are then no rainstorms to obscure the tracks. The sides of the chamber should be transparent in parts for viewing. A black cloth on the bottom of the chamber supplies a good background for viewing and also makes a better seal. The joints at the bottom and sides should be airtight to prevent convection currents. The bottom joints may be made airtight by having, on the bottom of the chamber, a pool of the liquid used in its operation. With the bottom and sides well sealed, the top joints do not have to be too perfect. A cloth is cut to overlap the inside of the chamber. This is sewn to a piece of metal screening, and is placed directly under, and in contact with, the metal top. The cloth, by hanging over the edge, provides a good seal at the top.

There must be some method to keep the dry ice in contact with the bottom of the chamber. All of the continuous chambers which I had seen in use had springs and a metal plate to keep the ice in contact with the bottom. However I found it simpler and more economical to place the ice on a wooden frame, on top of which the chamber rests. Gravity keeps the bottom of the chamber in contact with the ice. The wood insulates the ice in all other directions and thus prolongs its time of use.

I have designed and built three continuous chambers. The operation of each was similar. Wooden frames were used for the dry ice. Methyl alcohol, added through a few holes in the metal top, was absorbed by the cloth at the top. The metal top was heated and caused the alcohol to vaporize. I first used an electric iron to heat the top. Later I used a wire filament between two pieces of thin asbestos. The top does not have to be much above room temperature, 35° C. is sufficient. I have found that the momentary use of a photospot bulb heats the top well enough also. The tracks are viewed against light coming through a slit in a piece of cardboard.

Chamber #1 produced poor tracks because of convection currents from the poor seal of the sides. Also, its size was too large to maintain the proper temperature gradient. The angle iron which formed the sideframes to retain the glass made it impractical to use a sweep field.

Chamber #2 produced good tracks. Three-fourths of these were mesons, and the remainder were mostly beta particles. This corresponds correctly to the ratios of abundance of the types of cosmic radiation near the surface of the earth. The use of lucite which I drilled and tapped, made construction easier and provided a perfect seal at the joints. Lucite, however, is soft and scratches easily. It also becomes cracked on the surface with prolonged use of alcohol; therefore, photographs could not be taken through it with practicality. I was able to use this chamber in photographic experimentation by cutting a hole in the top and photographing through it. The base of chamber #2 was made of redwood and fiberboard. This was found to be more insulating than the pine and varnish finish of chamber #3.

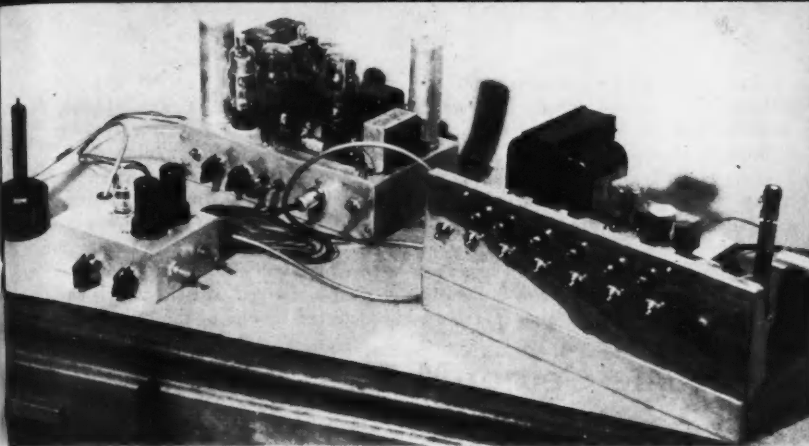
Chamber #3 gave the same track results as #2 did. By using a single piece of glass, the chamber, like #2, was completely free of convection currents. This chamber also had a hole in the

top for photographic purposes. The hole was covered with a glass plate. At first I removed the plate when I took an exposure, but by reducing the temperature of the top I was able to keep moisture off of the glass and was able to photograph through it. This improved the track quality by keeping dust out of the chamber.

The arrangement which I am using for photography supplies me with an almost parallel beam of light, which is sent through the transparent sides of the chamber, one-half inch from the bottom. The camera rests on the wooden frame above the chamber. Pictures are taken against the black cloth background with the light reflected from the water droplets. Because the light which is reflected at this 90° angle is very small, the photography is impeded.

The camera which I used is a Leica-35 mm. film—50mm. lens. A 5 diopter portrait lens gives an objective distance of 6½ inches when the focus is set for closest distance. The f-stop is f-3.5, the widest of the camera. The film which I use is Kodak Super XX. This has a tungsten rating of 64. After two trials I was able to secure photographs of the alcohol droplets. However the contrast was insufficient to allow printing.

I now have some Kodak Linograph Ortho 420, whose speed is 4 times as fast as the Super XX. Working with this film, and keeping the same f-stop and speed of 1/20 second, I hope to take printable photographs of tracks in my continuously sensitive diffusion cloud chamber.



➤ Geiger counter *built by Michael Dean Gainey, whose description of how he made it begins on page 56. He includes good advice on the use of counters.*

Atom Counters

➤ Until about 50 years ago, nothing would have seemed more unlikely than observation of a single atom. But discovery of radioactivity brought a method of detecting them singly, because radioactive atoms explode one by one. The rate at which these explosions occur is so constant for each species of radioactive element that it can be used to identify the isotope present. By charting the number of disintegrations in a certain time, it is even possible to distinguish several rates of radioactive change occurring at once. These can identify the individuals in a mixture of different isotopes.

Atom counters are instruments which have developed with the development of the new science of radioactivity. They have allowed us to learn more about this strange property of matter, to which the world has been exposed from its beginning. We have no natural senses to perceive the radiations given off by these atomic reactions, but we have just learned to build instruments which will recognize them and translate them into a language of numbers which we can understand.

Atom counters are primarily of two types. One kind uses a charged particle from the radioactive material to trigger an electronic circuit. This impulse appears, after passing through the apparatus, as the swing of a needle on an indicator dial, or registers in our ears as a sharp click. This type of instrument stems from the Geiger Counter, and has many variations.

The other type of instrument for detecting radioactivity is the Scintillation Counter. In it the charged particle sets off a minute flash of light when it strikes a chemical, usually

zinc sulfide, which has been found to have this unusual property. Several varieties of this instrument, also, have been developed.

As is well known, three kinds of rays are given off by radioactive elements. Alpha rays are streams of ionized helium. Beta rays are made up of electrons, which are units of negative electricity. Gamma rays are radiation similar to X-rays, with very short wave-length. These are all charged particles. They can be used directly to record themselves in one way or another on electrical circuits. Their differences can be used to make instruments which distinguish between them.

To count neutrons an isotope is used which will absorb a neutron and give off a charged particle, which can be detected by one of the counters.

The Geiger-Muller Counter

Michael Dean Gainey: The Construction and Operation of a Laboratory-type Geiger Muller Counter. Lowell High School, San Francisco, Calif. Honorable Mention, 12th S.T.S., 1953.

➤ One of the basic tools of the atomic sciences is the Geiger-Muller counter which is used to measure radioactivity in all types of applications from radiation monitoring to cosmic ray research. To construct a Geiger-Muller counter, I thought, would be one of the best ways to gain knowledge of both elementary nuclear physics and of laboratory techniques used when experimenting with radioactive materials. I consulted much reading matter with descriptions of G. M. counters, but I could find very little as to the actual circuitry from which I was to build the counter. However, "Experimental Nucleonics," by Bleuler and Goldsmith, contains all of the circuits necessary for construction, plus very fine descriptions of experimental techniques using counters. The circuits used in my counter are taken from this book, with certain changes that I found necessary to make.

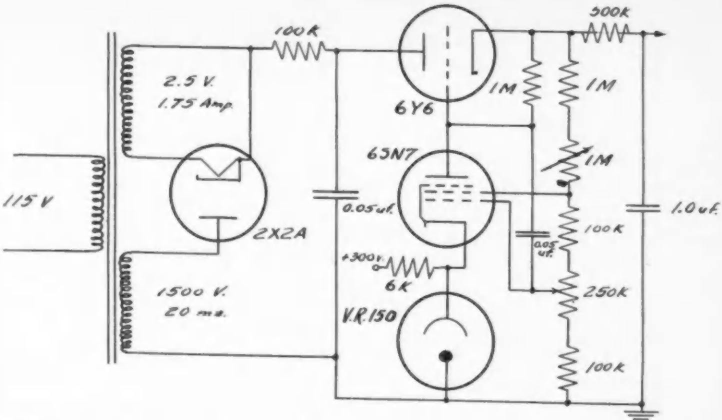
The power supply consists of a high voltage transformer, a half wave rectifier, and an electronic voltage regulator. The rectifier uses a 2X2A tube with ample filtering provided by a 0.05 mfd. and a 1.0 mfd. condenser.

The voltage regulator is of the cascade type. The regulator tube is a 6V6 and the regulating voltage is applied to the grid of this tube by a feed-back amplifier, a 6SJ7 tube. The cathode of the 6SJ7 is kept constant by a V. R. 150 voltage regulator tube which supplies the reference voltage.

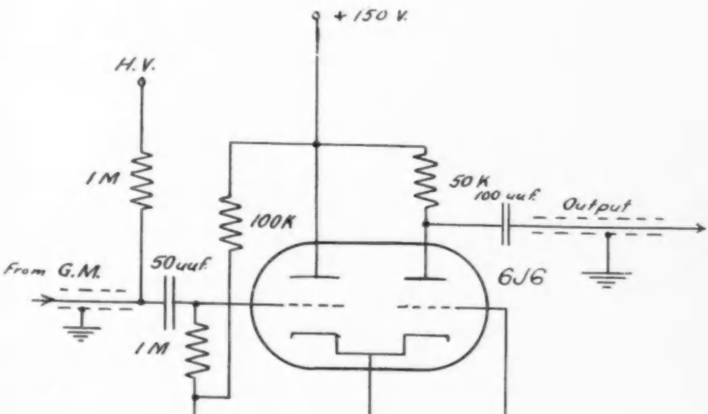
The input circuit consists, in my case, of a pre-amplifier and a discriminator or pulse-height-selector. The pre-amplifier uses a 6J6 tube, giving a gain of about 10, which is enough to drive the scaler when operated nearby.

The discriminator is of the Schmitt trigger type, using two 6AC7 tubes. It takes both positive and negative input pulses and has a rise time of a few microseconds.

The scaling circuit is based on the binary system, in which only every second pulse a tube receives is transmitted. By using several of these "flip-flop" circuits (in which a double



➤ SCHEMATIC *diagram of the high voltage supply for Gainey's Geiger counter.*



➤ DIAGRAM *of the pre-amplifier for the Geiger counter.*

triode, a 6SN7 in this case, has two stable states) in series, factors of two are gained, i.e. $2^6 = 64$ (six binary units in series transmit one pulse out of sixty-four). A Scaler is used to scale down the number of counts so that a relay-actuated mechanical register can record them accurately.

The output circuit uses a beam power amplifier, a 6V6 tube, which delivers a fast pulse to the mechanical register.

Many problems arose in building the high voltage supply section of the counter. To begin with, I tried to fire the V. R. 150 tube by tapping current from the output through the amplifier. To do this I reduced the 1 megohm resistor, which ties the plate of the amplifier to the high voltage, to a point where the V. R. 150 tube would fire. However, I could not get the tube to conduct enough without drawing almost all of the current from the output. This, of course, resulted in practically no regulation, so I had to add an external voltage source to fire the V. R. tube. I got this source from the supply to the pre-amplifier and discriminator by decreasing the bleeder current to the point where I had an extra 10 milliamperes of current with which to fire the tube.

Since I want to use a mica window G. M. tube in some beta-counting experiments, I had to increase my supply (which uses a 1500 volt transformer) to about 1250-1300 volts, which brings the voltage about 50 volts above the knee of the plateau of the G. M. tube (the optimum voltage for counting). However, the resistance values given in the circuit I referred to, were too great to gain maximum output, because the circuit was intended for use with a 2000 volt transformer.

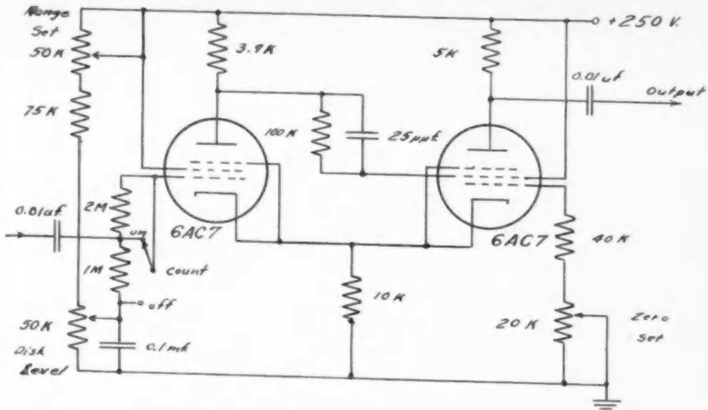
To increase the voltage, I increased the bleeder string by 0.5 megohm, and reduced the resistance in the filter system from 2 megohms to 0.6 megohm; this procedure also increased the A. C. ripple, but the discriminator prevents the ripple from reaching the scaler. I now have a variable supply ranging from 800 to 1400 volts maximum, which enables me to use both mica end-window G. M. tubes, and cylindrical glass-walled tubes.

Because I am operating the counter tube close to the scaler, a pre-amplifier is all the amplification I found necessary to drive the scaler. On the same chassis I built in a discriminator to eliminate any noise pickup, and in the future to run some proportional counting experiments. However, before I do any proportional counting, I will have to add an amplifier to the system.

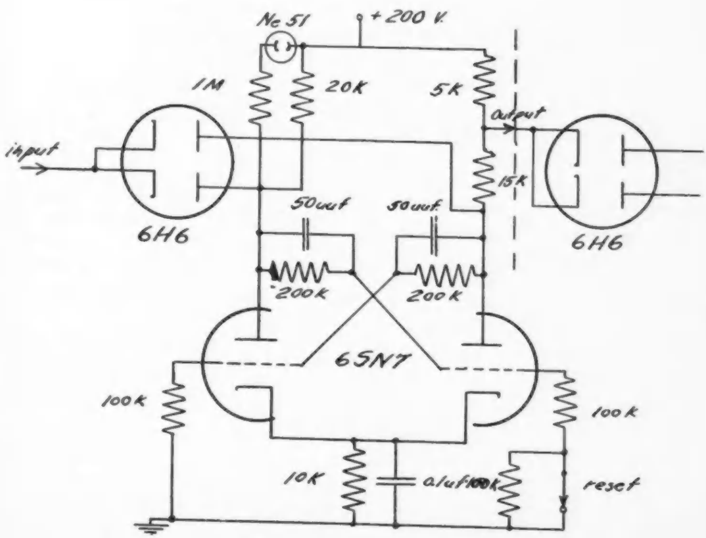
The scaler and output circuits were built on the same chassis with a common power supply for both circuits. The scaler worked well, the only problem being that of resetting the binary units. This problem was solved by raising the value of the reset resistors from 50,000 ohms to 100,000 ohms.

The output circuit does not deliver a large enough pulse to drive the mechanical register, which has a 110 volt coil, so a sensitive plate relay of 5000 ohms was put in the circuit and when it is actuated it closes a circuit of 110 volts for the mechanical register.

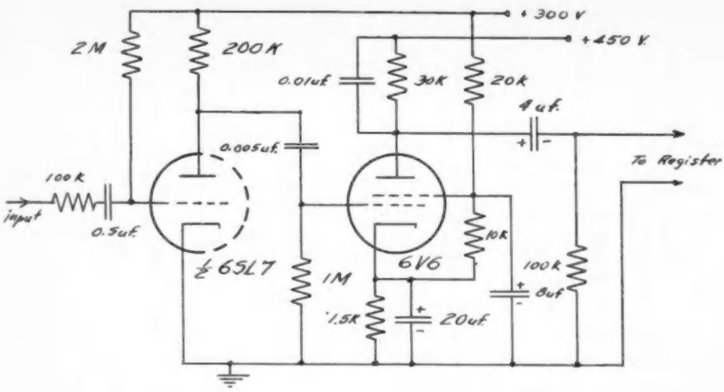
I have tested the counter with two types of tubes: a mica end-window



➤ Schematic *diagram of discriminator for Gainey's Geiger counter.*



➤ One binary *unit of the scaler for the Geiger counter.*



➤ SCHEMATIC *diagram of the amplifier, Gainey's Geiger counter.*

tube and a cylindrical glass-walled tube. As a testing source, I used 20 micrograms of radium which is used for skin treatments. The plateau slope of the cyindrical glass G. M. tube is about .03 per 100 volts, and that of the mica end-window tube is about .01 per 100 volts. The starting voltage of the mica tube is about 1125 volts and 850 volts for the glass tube.

There are a number of precautions to be taken when operating a counter to insure dependable operation and prevent damage to the counter. The proper steps in starting a counter circuit are as follows:

1. Be certain of the wiring.
2. Turn high voltage to zero while letting the rest of the equipment warm up. Warm up time should be at least 30 seconds.
3. Set switches for counting "on," and turn on the high voltage.
4. Increase the counter voltage slowly till the starting voltage of the tube is reached.
5. Advance voltage about 50 volts above the starting voltage which will make the counter operate just above the "knee" of the plateau.
6. Never exceed the ratings of a tube for a "continuous" discharge occurs above the maximum voltage and the discharge greatly shortens the life of the tube.

Almost all counting is done on the scale of 64, however, a selector switch for lower factors may be installed in the scaler.

The settings of the discriminator may be most easily determined by observing the pulse heights on an oscilloscope.

The Scintillation Counter

Edward Everett Gaines: Construction of a Photomultiplier Scintillation Counter. Tucson Senior High School, Tucson, Ariz. Honorable Mention, 13th S.T.S., 1954.

➤ AT FIRST I wished to build a portable counter, but it was soon evident that this was impractical for my purpose, as I could not, in several months of searching, find a transformer with a low voltage vibrator input that would supply at least 1000 volts direct current which is required by the photomultiplier tube. In this event, I decided to construct a stationary instrument, because the parts could be more easily secured and the stationary instrument can be made somewhat more sensitive than the portable one. In my search for parts I found that it was not as simple as I had thought to find a high voltage, low current transformer even with a 117 volt primary winding, as most of the commercial high voltage transformers are heavy duty plate transformers for radio transmitters, costing upwards from fifty dollars. This problem, however, solved itself when I was able to find a neon transformer rated at 2500 volts each side of the center tap and with a current rating of 20 milliamperes. Then with two type 1B3-GT high voltage rectifiers, a small filter condenser, and a series dropping resistor, I got around 1200 volts of slightly smoothed D.C. to apply to the photomultiplier.

To keep the cost of my project at a minimum, I used an RCA type 931-A multiplier tube in the probe. This tube, reasonably inexpensive, has been used by most amateurs in building scintillation counters, and is fairly easily adaptable to such a use. To get the proper voltage drop across the electrostatic amplifiers or "dyanodes" I used a voltage divider with 100,000 ohms per section. For shielding the tube, I used an aluminum i.f. transformer shield lined with lead, and the whole unit I sealed with black photographic tape. (The lead is to stop stray radiation)

The phosphors, which produce scintillations of light when irradiated, are, in this case, trans-Stilbene and Diphenylbenzene(para-terphenyl), procured from the Eastman Kodak Company. The latter phosphor, however, is used primarily in liquid scintillators, prepared by dissolving it in xylene or toluene.

In future experiments I intend to utilize a liquid phosphor and possibly some natural phosphors such as zinc sulfide and calcium tungstate (scheellite).

To further amplify the electrical pulse put out by the photomultiplier, I built a simple resistance coupled voltage amplifier, the diagram for which may be found in the RCA Tube Manual. In this amplifier, with a voltage gain of about eight or nine thousand, I did not match the resistance and capacitance in the input circuit to the decay time of the phosphor. I did not do this because with several different phosphors the decay time will be variable. I may have to modify this circuit to match each phosphor if I am to secure full efficiency from the counter.

To power the amplifier, I constructed a supply which delivers approximately 375 volts to the light load presented by the two tubes of the amplifier. This power supply is composed of a power transformer which delivers 330 volts each side of the center tap; a type 80, full wave rectifier; a choke input filter, consisting of a 4.2 henry choke and a 30 microfarad condenser; a series dropping resistor; and a bleeder resistor. The filter eliminates most of the hum from the power supply, and the resistances help to stabilize the voltage.

After having assembled all the parts, the next problem was to make them work. The units which gave me little or no trouble were the amplifier power supply, and the probe unit with the photomultiplier and its voltage divider. The amplifier itself, however, presented difficulties. The feedback which appeared was cured by running the input lead directly to the grid cap of the first tube rather than under the chassis. Then when I connected all of the units, except the high voltage supply, to a common ground, the hum stopped rattling the headphones. The high voltage power supply caused me much misery too, by either putting out an almost undetectable voltage or else over three times the amount that I wished. The latter case produced arcs at the output plug and inside the probe unit. This was remedied by grounding the negative lead at the "hot" end of the dropping resistor. The remedy, though, makes the h.v. supply chassis about 2500 volts negative with respect to the rest of the counter.

At present I am using a pair of headphones with the amplifier, but I have an arrangement by which the output can be connected to an oscilloscope, allowing visual detection.

Alpha Particle Detector

Lawrence Rosler: Visual Detection of Alpha Particles. Brooklyn Technical High School, Brooklyn, N.Y. Winner 9th S.T.S, 1950.

➤ THE HEART of the visual alpha particle detector is the detection chamber, illustrated in Figure 1. A type 931-A photoelectron multiplier tube is oriented so that its sensitized surface faces a cloth screen coated with fine crystals of zinc sulfide which is cemented to the interior wall of the chamber. An iron rod is mounted so that the extension of its axis intersects the screen at the point nearest the photocathode. This rod can slide along its axis by means of an air- and light-tight bushing, so that the distance from the screen to the radioactive substance placed at the end of the rod is variable.

In the operation of the detector, the material to be studied is cemented to the tip of the iron rod. Every time an alpha particle from the source hits the zinc sulfide screen, it produces a scintillation of blue light (wave-length approx. 4000A°) lasting approximately 100 microseconds. The strength of each scintillation can be determined thus:

$$\text{Energy per photon, } E = h\nu = \frac{hc}{\lambda};$$

$$E = \frac{6.624 \times 10^{-27} \text{ erg sec.} \times 3 \times 10^{10} \text{ cm./sec.}}{4 \times 10^{-5} \text{ cm.}} = 4.968 \times 10^{-12} \text{ erg.}$$

The energy of each alpha particle of the test substance (polonium) used for this part of the experiment is 8.43×10^{-6} erg. Thus, each alpha particle with full energy should produce 1.69×10^{6} photons, assuming 100% conversion efficiency, this value varying inversely as the distance from the source to the screen. Theoretically, therefore, at the cathode of the electron multiplier, each alpha particle should produce 1.69×10^{6} electrons. However, because the conversions from particle to photon and from photon to electron are extremely inefficient, very few electrons will be released from the photocathode for each alpha particle impinging on the zinc sulfide screen.

This group of electrons passes from dynode to dynode of the electron multiplier, increasing upon each contact because of secondary emission, until a pulse one million times greater than the original is collected by the photocell anode. This pulse is next amplified by a factor of 4×10^{5} by a three-stage amplifier (Figure 2) with a

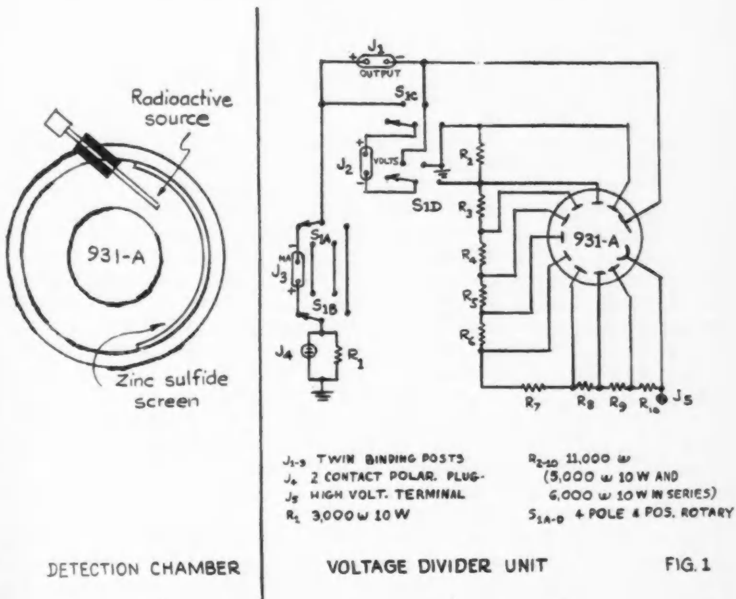
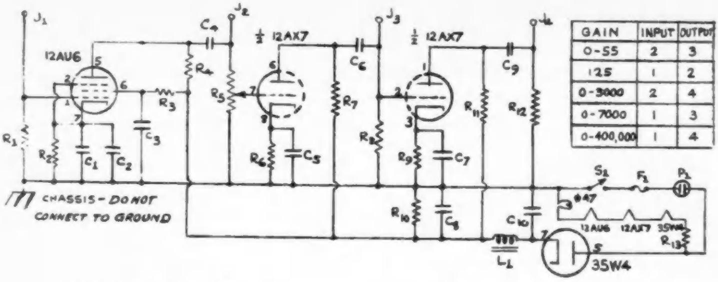


FIG. 1

➤ *Heart of the alpha particle detector built by Lawrence Rosler.*



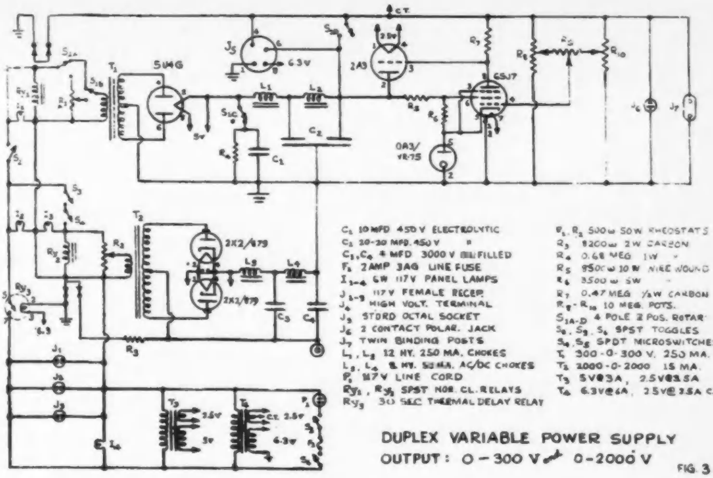
C_1, C_2 0.1 MFD 150 V PAPER
C_3 0.004 MFD " "
C_4 120 MMF CERAMIC
C_5, C_7 0.03 MFD 150 V PAPER
C_6, C_9 82 MMF CERAMIC
C_8, C_{10} 8 MFD 150 V ELECTROLYTIC
F_1 ¼ AMP 3AG LINE FUSE
J_{1-4} 4 POINT TERMINAL STRIP
L_1 8 HY. 50 MA. AC/DC CHOKE
P_1 RESISTOR LINE CORD
S_1 SPST TOGGLE

R_1 22 MEG.
R_2 3600 Ω
R_3 0.35 MEG.
R_4 0.22 MEG.
R_5 1.0 MEG. POT.
R_6, R_9 15,000 Ω
R_7, R_8 0.47 MEG.
R_{11}, R_{12} 2.2 MEG.
R_{10} 2500 Ω 10 W
R_{13} 330 Ω LINE CORD
ALL RESISTORS ½ W UNLESS NOTED

➤ THREE STAGE *amplifier in Lawrence Rosler's alpha particle detector.*

bandpass from 2,500 to 10,000 cycles per second. The amplifier thus passes on only pulses of from 50 to 200 microseconds duration, while rejecting all others. This selection greatly increases all interference from extraneous light sources which produce changes of less than 50 or more than 200 microseconds in length. The final pulse of electrons produces a voltage across a high value resistor, and it is this output which is impressed either on the vertical plates of an oscilloscope or into a counting mechanism. Each original alpha particle is thus represented on the screen of the oscilloscope by a narrow vertical "pip" whose height depends on the energy of the impinging particle.

It was found necessary to reduce the temperature of the multiplier photocell for operation at extremely low light levels so that the random thermionic emission from the photocathode and dynodes can be reduced as much as possible, thus eliminating a possible source of error in the operation of the detector. To accomplish this, the chamber is filled with dry ice to the level of the photocathode, and left for at least four hours to enable the elements of the electron multiplier to cool completely before operation. The carbon dioxide released from the dry ice as it evaporates rises rapidly to fill the entire chamber, expelling all the air already in the unit and preventing condensation of water vapor on any surface within the detector, a condition which is always a major drawback to reduced temperature operation. To prevent excessive entry of heat and consequent inefficiency of refrigeration, the walls of the chamber



➤ POWER SUPPLY *for Lawrence Rosler's alpha particle detector.*

were made of two concentric cylinders insulated between by glass wool.

The power supply for the detector was designed so that the high and low voltage outputs are completely isolated and continuously variable by rheostats R_1 and R_2 (Figure 3). These potentials are applied to the multiplier electrodes by the resistances contained in the voltage divider unit (Figure 1). In addition to the voltage divider, this unit contains a switching system providing for measurement of the operating conditions of the phototube by means of a vacuum-tube voltmeter and microammeter (Figure 4).

Among the advantages of the visual system over the older Geiger-Müller counter as used for the detection of alpha particles is the response of the latter detector to beta and gamma radiation, which causes a spurious count because of the ever-present cosmic rays. However, the zinc sulfide screen incorporated into the visual detector gives no response at all to either beta or gamma radiation, thus eliminating the background count. In addition, since the Geiger-Müller counter has a deionization time of about 5×10^{-4} seconds after each impinging particle registers, the count of particles arriving in quantities above two thousand per second is lost. Since conversion and secondary emission are instantaneous, the visual detector will provide a clear count at rates approaching one hundred thousand particles each second, the only limitation being capacitance effects in the electron multiplier and accompanying circuits. This rapidity of counting rate is of extreme importance in the determination of the radioactivity of substances such as Ra-

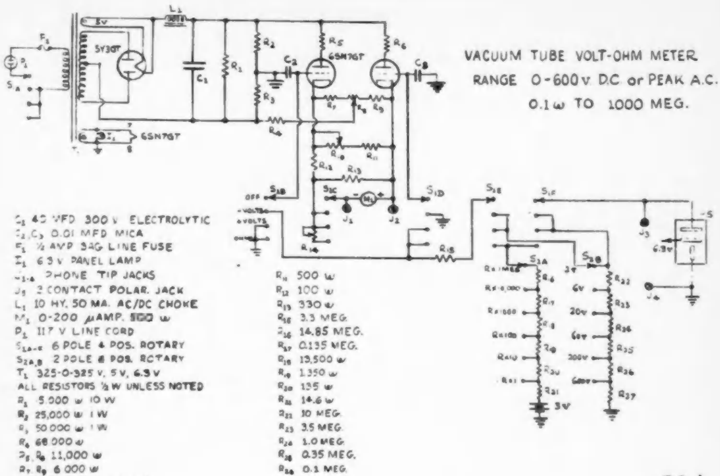


FIG. 4

➤ APPARATUS *for measuring the operating conditions of Lawrence Rosler's phototube in his alpha particle detector.*

dium C′, which has a half life on the order of 1.5×10^{-4} seconds. As this half-life itself is less than one-third the deionization time of the Geiger-Müller counter, that instrument would be valueless in researches concerning the Radium C′ stage of the uranium-radium series, or any other rapidly disintegrating substance.

The range of the particles may be determined and the radioactivity identified by the visual detector by gradually sliding the iron rod out of the detection chamber until the pips on the oscilloscope screen are indistinguishable from the tiny background shot effect pulses. Thus this apparatus can not only be used for determining the quantity and the strength, but also the range of the individual alpha particles emitted from the source. Because of the convenience and adaptability of this instrument as compared with others in use already, it represents a significant advance in the detection of subatomic particles.

➤ THE VAN DE GRAAFF *Generator built by Dennis Philip Malone, Kenmore Senior High School, Kenmore, N. Y., a winner in the Ninth Science Talent Search, 1950.*

Van de Graaff Generator

➤ STATIC ELECTRICITY was the first manifestation of electric energy that was known, but it remained a curiosity for thousands of years. Although Benjamin Franklin used it to play parlor tricks and to point up political arguments, and invented the lightning rod to render it harmless, it is really coming into use now for the first time.

With modern development of the science of nuclear particles, the immense energy that can be stored up temporarily in static machines has been put to work for particle acceleration. A favorite type of static machine now in use is that developed by Dr. R J. Van de Graaff of Massachusetts Institute of Technology, and named for him.

Although the mechanism for generating static electricity has become

more complicated since Franklin's day, the principle is still the same. Electrons are rubbed off a suitable substance by friction, and stored where conditions are best for building up the charge.

Van de Graaff's Design

The Electrostatic Production of High Voltage for Nuclear Investigations, by R. J. Van de Graaff, K. T. Compton and L. C. Van Atta, in The Physical Review, 43:3, 2nd series, Feb. 1, 1933.

➤ IT SEEMED desirable to develop an electrostatic high-voltage generator, since electrostatic methods yield directly a steady unidirectional voltage such as is desired.

Maximum simplicity was sought in the design. The simplest terminal assembly appeared to be a sphere mounted on an insulating column. Since the sphere must be charged and since the process should be continuous the charge carrier should approach the sphere, enter it, and, after depositing its charge inside should return parallel to its path of approach. This immediately suggested the action of a belt, a device long used for the transmission of mechanical power.

The logic of the situation therefore pointed directly to a generator consisting of a hollow spherical conducting terminal supported on an insulating column, a moving belt to carry electric charge to the sphere, a device for depositing the charge onto the belt in a region of low potential remote from the sphere, and a device for removing this charge from the belt inside the sphere and transferring it to the sphere. A refinement of these essentials was the addition of an induction device whereby charge of the opposite sign was carried by the belt on its return journey, thus doubling the current output.

A second refinement consisted of a self-exciting charging device whereby the entire generator could be made to operate independently of any external source of electricity. Not only does this device attain the desired result in what appears to be the simplest possible manner, but it is also interesting to note that the energy transformations in its operations are exceedingly simple, consisting only in the transformation of the energy required to drive the belt into work done in separating and transferring electric charge from earth potential to sphere potential.

Without Vacuum Acceleration Tube

Robert Tooper: 150,000 Volts in the Home Laboratory. Calumet High School, Chicago, Ill. Honorable Mention, 13th S.T.S., 1954.

➤ THE DEVICE decided upon was a modified form of a Van de Graaff electrostatic particle accelerator, used without the vacuum acceleration tube. A few words on the principles by which the machine operates will not be amiss, since they will facilitate explanation of several modifications which were later incorporated. A di-

rect current of fairly strong voltage is connected on one side to the earth as a ground, and the negative side to a metal brush or comb with pointed wires or bristles attached to it. This brush is in close proximity to a rapidly moving endless belt of some dielectric material. The two pulleys, at either end of this belt, are insulated from each other; in fact, the second or upper pulley is supported on a column built of some good insulating substance. Another brush, similar to the one below, removes the charge from the belt over its bristles of wire and conducts them to a large spherical or hemispherical conductor which completely surrounds the upper brush and pulley. The charges can neither escape from this terminal, because of its round shape, nor can they flow back to the ground, because of the insulating column upon which the entire upper apparatus is erected. Thus the charges accumulate until a great difference of electrical potential is established, whence a lightning-like discharge of energy takes place.

A recent adaptation of Van de Graaff's original machine as explained above was to install glass plates on the other side of the belt opposite the brushes, to which condenser plates, also with brushes (called inductors), were attached. With the belt revolving, the belt is touched lightly at a point a few inches above the lower inductor brush; friction knocks free some of the electrons in the belt, imparting to it a positive charge. The inductor replaces the electrons because of its condenser-like action; this creates a potential between it and the lower brush, which, instead of being connected in series with the D. C. supply, is now connected directly to the earth, grounding it. A reverse action takes place on the inductors and brushes within the upper sphere. The repulsion of the sphere inductor causes the charges to be hurled off the belt and onto the sphere with greater efficiency. In this manner, the generator will charge the sphere without aid from any external source of power.

It was at length decided to use a combination of these two methods. Further discussion of the theory behind the experiments requires first a description of the apparatus which was used.

Commercial apparatus: 1 General Electric Co. Type YU-2286-A3 Luminous Tube Transformer, Secondary Voltage 5000, Secondary Milliamperes 18; 1 Grigsby-Grunow-Hinds Co. D. C. Current Supply, output 180 volts at 50 milliamperes.

Besides the Van de Graaff itself, the equipment constructed at home also included a current pulsator operated by a twenty volt circuit so that the D. C. current supply could be used to operate the transformer.

Now to the construction of the Van de Graaff. A housing was constructed for the lower pulley and inductors from tempered masonite; the whole having windows cut into it for free observation of operations and brush effects. Both the lower and the upper pulleys turn on ball bearings extracted from an old pair of roller skates. A small induction motor has a rubber pulley attached to its shaft which imparts a retrograde motion to a similar pulley on the shaft of the lower belt roller, making a rolling friction contact with the second pulley.

The sphere assembly is supported on a hollow glass cylinder, eighteen inches tall and four inches in diameter.

This column is seated in a lathe-turned wooden ring mounted atop the lower housing. The sphere inductor equipment, which is similar to the other set below, is mounted on a wooden disk rabbeted so as to seat itself atop the cylinder.

The spherical conductor itself was manufactured as a tank float. The hemispherical shapes of pure copper, two in number, were soft soldered together, after which they were placed in a plating bath and the solder covered with a layer of copper. The ball was then polished with fine emery paper, crocus cloth, and jeweler's rouge; and a hole of such size as to fit a rabbetted lip on the top wooden disk was cut out with a circle cutter.

Inasmuch as the operation of the generator on pure static electricity has already been described, I shall discuss operation on the somewhat-more-than 5000 volts D. C. provided by the tube transformer, in combination with the old inductor system. The negative terminal was connected both to the ground and to the ground brush terminal; the positive wire being connected to the inductor.

After the current supply and the pulsator were placed in operation, the motor of the generator was started. Within two minutes, a bright, fat, two inch spark was drawn from the sphere by a ball bearing connected with the ground.

After several days experimenting on the machine while it was connected in this manner, and being able to draw only a three inch spark at most, I reasoned that it might be possible to improve the output of the generator and decrease the charging period considerably if it were possible to operate on 5000 volts A. C. provided by connecting the luminous tube transformer directly to the house line instead of two terminals on the current supply. I reasoned that, since the electric current is believed to consist of the flow of electrons through a wire, no matter which way the electrons were going, they would still be able to discharge themselves through the bristles of the brushes onto the dielectric belt. Following this hypothesis, one terminal of the transformer was connected to the ground and to the ground brush, the other to the ground inductor, the transformer turned on, and the motor started.

The results were most encouraging. Within thirty seconds the sphere was fully charged, causing the experimenter's hair to stand on end, and a spark approximately six inches long was drawn from the sphere. This on a day when the atmospheric humidity had greatly risen.

The sparks produced were of two kinds: First, a strong variation of the brush discharge: fuzzy and not too distinct, but distinguished from it by its length, its momentary existence, and its fairly loud report. The second, which is drawn usually immediately after the first, and slightly shorter in length, is much brighter, stronger, and gives a crashing sound upon discharge. The length of the sparks suggests an output in the generator of about 150,000 volts of electromotive potential difference between the sphere and the ground.

With Plastic Column

Laurence Frederick Schmoyer: The Van de Graaff Generator. Allentown High School, Allentown, Pa. Winner, 12th S.T.S., 1953.

➤ THERE WERE many problems to be overcome, so I started to get to work on them. Slowly and with many hours of work the machine took shape. The bearings were bought in an army surplus store and the rollers were turned out in the high school machine shop. Instead of glass, plastic parts were used as they are easier to shape. There were some *ersatz* parts such as friction brushes made from old suede shoe brushes and a copper sphere fabricated from a roof decoration used on houses. The wooden parts were the most difficult to make as some of them required complex shaping. The bearings were mounted in wooden rollers, the base and sides were mounted, the brushes were attached, the plastic parts were bought and shaped, and finally the whole thing was put together.

The completed machine looked somewhat like a man from Mars. The broad black base supported a transparent column of plastic through which the moving silk belt could be seen. The column, in turn, supported the upper brush assembly and the copper sphere where the charge is collected.

To my satisfaction I received a shock that made those one receives on a winter night, after shuffling across the floor, seem puny. The smell of ozone produced by the blue sparks seemed wonderfully good; the machine worked well from the beginning.

Since it requires 67,000 volts to produce a spark one inch long and under favorable humidity conditions the machine produced a spark two inches long, the generator has an output in excess of 100,000 volts.

Just as in all other static machines, the Van De Graaff depends on friction. As the motor turns the belt, some electrons are knocked from it by the lower brush assembly and impart a positive charge to the belt. As the belt continues to turn, this positive charge is transferred to the sphere where it is removed from the belt by the upper brush assembly. This process is continuous and after a few revolutions the sphere is completely charged. The sphere will hold the charge a considerable length of time and as one approaches he can hear the electricity sizzle as it jumps from the machine to his body. The capacity of the machine is determined by the size of the metal sphere on which the charge is deposited from the collector. My machine has a copper sphere of 7 inch diameter. The silk ribbon is driven by a $\frac{1}{4}$ HP, 1725 RPM electric motor. I had to provide an adjusting screw for leveling the wooden roller on which the belt moves, to keep it centered.

The major application of this type of generator is in atomic research where an area with no electrical charge is needed. Gigantic generators with ten foot diameter spheres are used. The sphere shape is used because charged particles tend to leak from irregular or pointed objects.

Electronic Computers

➤ In the so-called "mechanical brains" recently devised for large-scale counting, the speed of the electron is harnessed to take the drudgery out of computation. In designing electronic circuits which can duplicate the fundamental processes man uses to add and subtract, to multiply and divide, to raise to powers and extract roots, physicists have learned new ways of looking at other thought processes.

Machines count by methods different from those children learn in grade school. But mechanical arithmetic is becoming commonplace. Subtraction by adding the complement, the method used in ordinary computing machines, has almost joined the classical methods taught in the "three R's." Binary computation, carried on with the characters 1 and 0 only, is the technique used in electronic calculators. It, too, is coming to be well known.

The limitation of the electron tube, which either does or does not let an electric pulse pass through, is responsible for choice of doing arithmetic with 1 and 0. But, although the resulting numbers are long, ordinary arithmetical problems can be worked in this system with no great difficulty.

The "either-or" mechanism of the electronic computer circuits also leads by analogy to study of problems of cause and effect.

Circuits with a choice of multiple paths are easy to construct. Electric switches can be made to operate in sequence, so that choice of one combination leads to a different result than that arrived at if a different choice were made. Such sequences seem to carry out processes close to those of thinking. Logic is being reviewed in the light of new understand which man is getting from the machine.

It is no wonder that young people find great fun in the planning and wiring of some of the elements of the new computing machines. Besides counting and logical deduction, electronic circuits can carry out a number of successive tasks, and can even take on a human opponent in a game of tic-tac-toe.

Electrical Digital Computer

Gilbert Michael Dunne: An Experimental Relay Calculator. Teaneck High School, Teaneck, N. J. Honorable Mention, 11th S.T.S., 1952.

➤ The assistance I received in this project came from one of my former teachers who was interested in this field.

I began by reading all the material I could find on the circuits of existing mechanical brains. We pored through all the ideas I received and decided what we could actually do.

Calculators are of two types: analog computers and digital computers. The analog computers change the numbers

given to them into physical characters. For example, perhaps the simplest analog computer is the slide rule. It changes numbers into length. An analog computer does its work in this physical medium, and then reconverts the medium — such as length or the amount of turning of an axle — back into numbers.

Digital computers handle numbers as numbers. They in no way change the numbers into something with great variance; rather they use a code, with nothing smaller than a given unit, and build up upon this. The simplest digital calculator is the abacus.

I decided to build a digital machine. It would be electrical in nature, rather than mechanical.

All the digital machines constructed up to that time — February of 1949 — had employed either vacuum tubes similar to those used in radios, or relays. We decided it would be simpler and less expensive to use relays.

Relays are electro-magnetically controlled switches. A relay consists of an electro-magnet which, when an electric current passes through it, attracts an armature made of soft iron. When this armature moves it opens or closes sets of contacts.

We decided to make the project long-termed and with no definite limits. The work would be done in the school, in a separate portion of one of the science rooms.

Since relays were to be used in this calculator, I set about finding some. The main requirement was that we must find many similar ones, and that they be inexpensive.

Mr. Madsen, my instructor, was able to locate several old pin-ball machines. From these we salvaged all our relays. We next settled down to designing the circuits for the first unit.

The first unit, as originally planned, was to be an accumulator, that is, a mechanism which adds.

These relay calculators employ binary numbers, in which only two characters are used, 1 and 0, compared with the 10 of the decimal system. The numbers, instead of operating on powers of ten, would operate on powers of two.

This first unit was to be able to "understand" numbers up to the second power, that is, 2^2, or 4. However, as the circuits were designed, we decided it would be better to start with a larger unit, and we began design for a unit which would "understand" up to the fourth power—2^4—16. These plans were drawn and redrawn, in order to have as a result the most economical plan. Our final diagram required thirteen relays.

Actual construction began by mounting the relays on a rack, a very simple rack, consisting of a piece of angle aluminum. Then the wiring began.

In order to have this work we needed a power supply. The relays required from ten to eighteen volts each at direct current. The school system of voltages for the laboratories was pressed into service. With this we began testing and adjusting, retesting and readjusting, until the unit worked.

Our next construction would be a unit to store these numbers. Relays do this also. After a number is stored, if it is desired, it may be sent to the accumulator. There it is added to whatever is in the accumulator al-

ready. But should we want to subtract that stored number, we make use of a method often used when working with logarithms—the "ten's complement." In actual practice it is wiser to use a "nine's complement," because of the nature of binary digits.

To do this a special set of contacts are added to the storage or memory relays, which may be called into use whenever desired. A number recalled by these contacts is not the number originally stored, but is the nine's complement.

All this was taken into consideration when our first memory unit was designed. It would be capable of storing two four binary digited numbers (from 0 to 15), and by placing electrical impulses at the proper place, would release a number to be added or subtracted. It used twelve relays and eight rectifiers. Rectifiers are small units which permit an electric current to flow in only one direction.

When this was constructed, the steps followed were similar to those used in constructing the first unit. A similar rack was used, the wiring was done, the unit was tested, retested.

In order to correlate the two units, a control or programming board was set up. This was to take the form of an array of switches which would connect the units in different ways. In this unit, built to cover only our immediate needs, we used fifteen switches, some of which were of the type which return to their original position when released. Lights were included to signal the answer.

These switches were divided into five groups. One group was used to insert numbers into the machine. A second group controlled the destination of a number being entered or transferred. A third group controlled the choice of point of exit of these numbers — either from one of the two memories or from the accumulator. Other switches controlled the locking and erase circuits for destroying numbers, and the add or subtract circuit.

A frame was built and to this the racks were attached. The units, coordinated by the control panel or programming board, worked together.

As we continue putting work into the calculator it grows. I have drawn plans for units which will:

Punch paper tape into code form to feed information to the machine.

Read the tape and feed it into the control panel, making it unnecessary to throw the switches there.

Store more numbers.

Multiply two numbers together.

Divide two numbers.

Compare two numbers, and tell which is larger.

All these things I hope to incorporate into the machine by the time I leave the school. It will then be capable of almost all the operations of a much larger, much greater, and much more useful electric brain.

Similar units might be constructed by those who have to learn to operate large electronic brains. It is its small size and relative simplicity that permits one to understand it all at once, which is more than can be done with any great calculators.

➤ Ultrasonic vibration *causes an oil fountain when the transducer is operating at the third harmonic. The photograph was taken by Kirby Vaughn Scherer, Jr., who describes his apparatus in the accompanying report.*

Ultrasonics

➤ Animals can hear sounds of higher pitch than those to which human ears respond. But, far beyond the range of any hearing, it is possible to transmit vibrations of the same type as sound waves and experiment to see what they can do. These ultrasonic waves act with energy which can break up chemical compounds, emulsify materials that usually do not mix, and perform other stunts. The apparatus with the vibrating crystal that generates these ultrasonic waves is known as the transducer.

Ultrasonic Vibrations

Kirby Vaughn Scherer, Jr.: Some Laboratory Experiments with Low-Powered Ultrasonics. Benjamin Bosse High School, Evansville, Ind. Winner, 13th S.T.S., 1954.

➤ WHEN THIS experimenter first became interested in the production and effects of low-powered ultrasonic waves, the question arose as to the best means of generating them. Because this interest was centered largely upon the thermal and agitation effects, the field was immediately narrowed to piezoelectric transducers. Magnetostrictive transducers are limited to relatively low ultrasonic frequencies, not exceeding 200 kilocycles, and other methods are suited only to gases. The desired effects occur mainly at frequencies greater than this.

A number of substances are available for use as piezoelectric transducers, but for several reasons a polycrystaline form of barium titanate was selected. As compared to quartz, the classical material for these applications, it has several notable advantages. First it is a low impedance material, requiring driving voltages of a hundred or less, compared to tens of thousands of volts for quartz. Equally important, the piezoelectric coupling coefficient, expressing mechanical strain per applied electrical stress, has a value about five times that of quartz. And of significance to me, the cost is considerably lower, especially regarding the thick plates used for ultrasonics. Accordingly a transducer element 1.5 inches in diameter and .26 inches thick, with a fundamental resonant frequency of 400 kilocycles, was purchased at a cost of $10.

This is plated on both faces and is a piston type of vibrator. The waves produced are of the longitudinal type, that type being most satisfactory for the usual applications. In the piston type vibrator, where the radius of the piston is great as compared to the wavelength, the angle of dispersion is quite small, most of the sound being propagated normal to the face. The sound intensity normal to the face of the piston is directly proportional to the frequency and the area of the piston, and inversely so to the distance along the normal. In the case of a given disc, the sound intensity at an angle to the normal is a function of the sine of that angle.

In regard to generating the radio frequency driving power, the main characteristic of vacuum tube oscillators for this purpose is their extreme simplicity. For my purpose a shunt-fed Hartley oscillator circuit was constructed using two RCA-807 transmitting tubes. The screen and plate were initially tied together and the tubes used as triodes, but much better operation resulted when a 30 K ohm resistor was employed to bias the screens and the tubes operated as tetrodes. If the ultrasonic waves are to be primarily used for agitation, the oscillator may be driven directly by a step-up transformer, although somewhat better efficiency results with DC input. I used a rectified supply with a condenser input filter, furnishing about 700 volts at 200 milliamperes.

Later, in an effort to secure greater ultrasonic energies than could be obtained from two 807's, an obsolete diathermy machine, equipped with two 211 triode transmitting tubes, was purchased. This originally had a multivibrator type of circuit not suitable for conversion to a lower frequency. Therefore, it was rewired as the aforementioned shunt-fed Hartley circuit, using the original components. It is powered by a step-up transformer directly from the AC mains, so the output is modulated by a sixty-cycle sine wave. Because the physical dimensions of the chassis do not permit a tank circuit large enough to reach the fundamental of 400 kilocycles, this machine has thus far been operated on the third harmonic, or 1.2 megacycles. As the original machine included a dual range rf milliammeter, direct measurements of transducer current are possible.

The best method of coupling the transducer to the oscillator so far discovered is to connect it directly across several turns of the tank circuit. Tapping across six turns of a 75 turn coil would result in about 100 volts rms across the transducer, if voltage is divided uniformly among the turns. Rf current runs upwards of 1000 milliamperes in the more powerful unit, so this would result in approximately fifty watts of sound energy, as this material converts more than half of the applied electrical stress to mechanical response.

For mounting the transducer, I first used the holder described by Arthur Laufer, in *Electronics,* March 1951, but this proved cumbersome, so I constructed the holder shown in the photograph. An air chamber behind the transducer effectively reduces loss of energy to the rear, as air is a relatively poor conductor of sound waves at these frequencies. Thus practically all the output is concentrated in the forward direction. The transducer is driven under mineral oil, to secure good transmission of sound energy and low rf losses.

When the rf energy is supplied to the transducer, a low mound a few millimeters high rises over it, with drops of oil being flung several centimeters above the liquid. When the frequency is raised to the third harmonic, and the transducer lowered until it is about ten centimeters below the surface, the mound resolves into a single jet of oil squirting three to four centimeters above the surface. An exploring finger placed in the oil at the point where the jet rises above the surface must be quickly withdrawn or a burn will result. This concentration is attributed to constructive interference along the normal to the center of the sound source. Using the 211's, I have observed an oil fountain averaging five to six centimeters high, with occasional droplets going as high as fifteen centimeters. Heating is quite rapid here, the temperature rising to 60° C in a very few minutes, so I have been forced to detune the oscillator slightly for experiments requiring prolonged agitation.

The material to be treated is placed in a thin-walled test tube and lowered into the oil a short distance above the transducer. In an effort to secure better transmission of sound energy, an open tube was tried with a polyethylene diaphram stretched over the bottom. Time for the production of dispersions appeared to be decreased;

however, this decrease was not significant.

If a test tube of water with a few drops of mercury at the bottom be placed over the sound beam, the water darkens to a brown color as minute droplets of mercury are flung violently into suspension. If this suspension is examined under a microscope, the particles of mercury are seen to exhibit a Brownian motion. Settling occurs over a period of several days, but the particles do not re-unite, as evidenced by the fact that the liquid regains its original appearance if shaken. Exposure to higher sound energies would doubtless give a more lasting suspension.

Oil-water emulsions occur in much the same manner, but due to the lesser difference in density, settling is slower, requiring several weeks. When a test tube containing dissimilar liquids is placed in the sound beam, the emulsification occurs first at the boundary layer, both liquids becoming clouded at this point. It was noted that emulsification occurred more readily at the fundamental than the third harmonic, so experiments of that sort were carried out at 400 kilocycles. The unit I constructed is too low-powered to achieve emulsification in a practical length of time. In addition, the transducer temperature begins to rise, so action must be stopped. Barium titanate loses polarization and becomes inactive at a temperature of 95° C, so care must be taken to see that this figure is not approached too closely.

One effect mentioned in the literature is the decrease in germination time of seeds. To test this, radish seeds were exposed to ultrasound for periods of up to ten minutes, control seeds being heated to the temperature reached in water for equal periods of time, and all planted in sterile sand kept moist with nutrient solution. Although the exact records of this experiment have been lost, I recall that the treated seeds germinated a significant number of days earlier than the controls, and that exposure times of greater than two minutes effected no more decrease in germination time.

Of greater interest to me are the chemical effects. Some of the more significant ones reported are the depolymerization of high polymers (Sobue and Ishikawa, *J. Society Textile Cellulose Industries,* 5:366) and oxidation reactions of various kinds. Alfred Weissler has reported that if a potassium iodide solution-carbon tetrachloride mixture is subjected to high-intensity sound at a frequency of one megacycle, iodine is set free. He attributes this to the freeing of chlorine, which then oxidizes the KI. I repeated this experiment at 1.2 megacycles and after several minutes the water assumed a brown coloration and the carbon tetrachloride a pink hue, both characteristic of free iodine.

As the action of powerful ultrasonic waves causes changes in high polymers, I would expect it to affect the products of a condensation or polymerization reaction, in regard to products or reaction rates. It would seem to me that if polymers were prevented from forming in a reaction that ordinarily results in them, entirely new and different products might result.

➤ STROBOSCOPIC *effects were photographed by Alan J. Fletcher, Nelson W. Aldrich High School, Warwick, R. I., for his exhibit in the First National Science Fair, 1950.*

Stroboscope

➤ RAPID MOTION is stopped, as far as vision is concerned, when blinking lights or shutters allow a peep at the moving object only at the instant it reaches a certain point in a repeated action.

A slit in a disk revolving at the same rate as a wheel gives a glimpse of the wheel whenever it passes an observer's line of sight. Thus the observer sees the same part of the wheel whenever it comes around. Persistence of vision, the same trick that gives us moving pictures, shows this spot continuously, seemingly standing still, even though it is actually travelling at high speed. The wheel being watched must be illuminated, and another way to make it appear to stand still is to flash a light on it whenever it comes around, instead of cutting off the constant light with the slit disk.

Either way, the device is known as a stroboscope. It can be used for many purposes. Many interesting effects can be made by varying slightly the speed of the stroboscope, so that the apparent motion is varied, slowed up, reversed, and made to do tricks.

How to Get the Stroboscopic Effect

Harvey L. Goldberger: The Stroboscope and the Stroboscopic Effect. Brooklyn Technical High School, Brooklyn, N. Y. Honorable Mention, 11th S.T.S., 1952.

➤ THERE ARE two methods by which one can achieve a stroboscopic effect (the apparant stoppage of revolving, rotating or reciprocating motion). The first of these methods which is mechanical, involves the use of a disk with one or more evenly spaced narrow slits cut near the circumference of the disk along its radius. If one looks through these slits at a rotating object while the disk itself is rotating at the same speed or a fraction thereof, depending on the number of slits (one slit — equal to object speed, two slits — one-half object speed, three slits — one-third object speed, and so on) the object will appear stopped. However, this method has several drawbacks which make it impractical:

(1) Its speed cannot exceed a certain limit without the danger of the disk breaking up from the great centrifugal force produced.

(2) Unless it is rotating at a fairly high speed the image will tend to blur.

(3) It is inherently clumsy in that it cannot be easily moved around and cannot reach into tight spaces.

The second method, and the one I used myself, is electronic in nature. It involves the use of an oscillator which delivers a controllable number of extremely short electrical impulses (5-10 microseconds) per second which in turn are used to flash the strobotron tube. Again, when this flashing light is pointed at a rotating object moving at the same (or an integral multiple of) speed at which the light is flashing, the object will appear motionless.

CONSTRUCTION: Not having had any previous training in the design of electrical circuits, I was forced to copy, with some modifications, a design published in the September, 1948 issue of *Radio and Television News,* page 38. The parts required were relatively inexpensive, about $15 in all, and the result was a small, portable stroboscope whose frequency range and light output were sufficient for my purposes.

The circuit itself consists of two sections. The first, the voltage doubler power supply circuit, converts the 115 v. A.C. house current to D.C. and then multiplies it between $2\frac{1}{2}$ and $2\frac{3}{4}$ times, supplying to the oscillator circuit about 300 v. D.C.

The oscillator is of the relaxation type with the strobotron tube, at the end of a five foot long cable, as an integral part, and the frequency control being originally a 1 megohm potentiometer with a 300° rotation of the dial. Since the frequency range as given was fairly narrow, 10-112 f.p.s. (flashes per second), I proceeded to modify the circuit in an attempt to broaden it. First, I removed from the circuit R_4, a 50,000 ohm resistor in an attempt to raise the frequency range. However, although this was accomplished it produced unsatisfactory results since it left about one-third of the band without any observable con-

trol. That is, at a point about two-thirds of the way around the dial the frequency would suddenly jump from about 500 f.p.s. to about 800 f.p.s. and remain at that frequency until almost to the end of the dial at which point the "strobe" tube would cease to arc but merely would glow. Moreover this deletion of a resistor also raised the lower frequency limit above its former level of 10 f.p.s. to a new level of about 25 f.p.s. Therefore, although the frequency limit was raised by the removal of 50,000 ohms from the circuit, the total effect was to compress an expanded frequency range into a smaller space than previously (i.e. 10-112 f.p.s. in a 300° rotation of the dial, as compared with 25-500 f.p.s. in a 200° rotation of the dial). Obviously, a value somewhere between 0 and 50,000 ohms was necessary to remove the wasted space from the dial. I therefore inserted into the circuit at that point, a number of resistors (taken from an old radio set) ranging in value from 14,000 ohms to 1200 ohms. The 1200 ohm resistor (later tested and found to be 1400 ohms) proved to effect the desired result. However, I still wished that the lower frequency (which was now about 20 f.p.s.) limit be extended below its present level. Since it was obvious that nothing more could be done here, I proceeded to design a simple extension of the circuit, encompassing a 2 megohm potentiometer and three 220,000 ohm resistors connected in series; that is, after several trials had been performed. The resistors were later measured and found to total 840,000 ohms or 280,000 ohms per resistor. This extension was connected to the major circuit by means of double pole, double throw toggle switch. Thus, when the 'low' circuit was hooked in, the 'high' was not, and vice versa. This arrangement gave an effective frequency range of about 8-500 f.p.s. (i.e. 8-24 on the low and 20-500 on the high band, and with a "cushion" formed by the frequencies 20-24 f.p.s. which appeared on both dials). This range is broad enough to cope with almost any situation.

It is obvious that in order to use the stroboscope to its fullest extent (i.e. to establish the r.p.m. of an unknown motor etc.) one must have some specific knowledge of the flash rate at specific points on both dials. The prescribed and most accurate method of calibrating an unknown oscillator requires the use of a known oscillator as a frequency standard and an oscilloscope as an indicator.

Since, however, I did not have the money necessary to buy or rent this equipment, I was forced to devise my own cheaper, if less accurate, method of calibration. This required the use of a camera with a fast lens (f/3.5), which I already possessed, a fast film (Kodak Super XX), and a spherical neon bulb which I borrowed.

The calibration proceeded as follows:— First, the strobotron tube was attached just above and at right angles to, the neon bulb, and in turn the two were wired to the top of a four foot pole. The loaded camera, with the lens set at the widest aperature, was then set up on a tripod three feet from the pole. At this point the room lights were turned out, the neon bulb plugged in, and the stroboscope set to its lowest flash rate and turned on. Then with the camera shutter open,

I pivoted the pole on its bottom across the field covered by the camera lens, and then closed the shutter. Now, the plates within the neon bulb are in the shape of two opposed semi-circles, and they flash on and off alternately at the rate of sixty times per second each (60 cycle per second house current), with no time lapse between flashes. Therefore, if this bulb is propelled across the field of vision at a great enough velocity, as it is across the camera field, the semi-circles will appear to separate, an effect readily discerned by the human eye. Obviously, the film will record the image of the neon bulb in the same manner. Similarly, the "strobe" tube, flashing at a given number of times per second, and moving swiftly (in a vertical position) across the camera field will produce like images of itself. Therefore, since the "strobe" tube and the neon bulb are in this case moving together across the camera field, their images will appear together on the film.

The time elapsed between two corresponding points is one-sixtieth of a second. Thus, to calculate the flash rate one merely has to count how many flashes occur in how many sixtieths of a second, and then multiply the number by sixty to get the number of flashes per second. This may be done at as many points as is desired.

However, this method is at least slightly inaccurate. The flash rate seems to follow no particular pattern in relation to the resistance, and all attempts to form a relationship between the two have ended in failure. However, I am quite sure that in all actuality there is a very definite relationship between the two.

There are many possible causes for these inaccuracies. Among the most likely are:

(1) The voltage in the A.C. power line varies somewhat, thus changing the flash rate of the stroboscope at any particular point. (2) It is sometimes quite difficult to count the number of flashes per sixtieth of a second (i.e. one flash in seven-and-a-quarter (?) sixtieths of a second).

However, since to the best of my knowledge the prescribed method is the only accurate one, and since it is not available to me at the moment, I feel that the above described substitute method is at least as good as any other less than perfect method, and there is an advantage in the fact that the film can serve as a permanent reference.

The uses of the stroboscope are many and varied. Perhaps the most obvious application is the use of it to "freeze" a fast moving revolving, reciprocating, or rotating object. However, it is probably better used merely to "slow up" a rapidly moving object, since by doing this one can observe complicated motions, such as the action of a valve spring or a sewing machine, which otherwise could not even be seen. To slow up a moving object with the "strobe" light, one only has to set the flash rate slightly under the object's r.p.s. or v.p.s., to set the object moving "backwards," set it slightly above. Also, it may be used to indicate defects in an object which do not present themselves while it is at rest. For example, a flywheel may have a slight crack in it, which,

however, does not open up until it is rotating at a high speed. This is easily observable by means of the "strobe" light. Another important application is in the measurement of motor speeds. One only has to "stop" the motor spindle and read its r.p.s. right from the stroboscope's dial.

If necessary, a rotating object could be photographed while "stopped," by using the stroboscope as a light source, with a long film exposure to compensate for the low light output. I myself attempted to photograph a rotating object in the above manner, but the results were unsatisfactory since the speed of the motor I was using was in a state of constant oscillation, thereby producing a vibratory motion at the ends of the object (a propeller), spoiling any chance for a photograph capable of being studied.

Professor Edgerton, of M.I.T., one of the original inventors of the stroboscope, has, within the last few years, developed a new model which has an extremely high light output, high enough to take pictures by without a multisecond exposure time. This development has led to the study of motions such as a golf or a baseball swing, showing the club or bat in many positions along its line of flight.

Finally, there are several interesting phenomena which are brought about by the use of stroboscopic light. If a "strobe" light were pointed at a thin stream of falling water, it would not appear solid as it would under ordinary light, but as it really is, a myriad of individual drops. Also, when the stroboscope rate is a "harmonic" of the machine speed, multiple images will be seen. For example; if the stroboscope rate is four times the speed of a two blade fan, four blades will be seen standing still.

Experiments With Stroboscopic Light

Robert L. Farrington: My Experiments With Stroboscopic Light. Fairfield Preparatory School, Fairfield, Conn. Honorable Mention, 13th S.T.S., 1954.

➤ The principle behind stroboscopic light lies in its ability to deceive the human eye. The light, flashing at regulated intervals, catches motion at one certain phase. For example, using the stroboscope on the rectangular nut at the end of the shaft of a motor, I was able to catch the nut in a vertical position and make it appear completely stationary, although it was actually revolving at approximately 2000 rpm. By changing the size of the slits, the acuity afforded the observer can be either increased or decreased. For instance, by using a smaller slit, I made the image sharper but in using smaller slits, I found that a portion of the light is lost, and thus, the target was not illuminated as well.

I obtained a metal disk, 8" in diameter, and mounted it on a variable motor. For my lighting source I chose a carbon arc lamp because of its brightness. In my first experiment I cut four slits, 3/4" x 1/16", in a metal disk. These slits were all the same distance from the edge, about 1/2". Placing the motor in front of the arc lamp, I fitted a piece of cardboard with a

slit in it in front of the lamp, thus eliminating stray light. I then turned my stroboscope on a wall fan, and was able to reverse the direction of the fan and slow it down so that it clearly appeared to have six blades instead of the three it actually has. This was due to the fact that my disk was revolving twice as fast as the fan.

My next experiment was with water drops. I turned the stroboscopic light on a dripping faucet and the shadows of the drops appeared to move upward. I found that it was easier to watch the experiment by watching the shadows instead of the actual drops. By increasing the speed of the water to a thin, steady stream, I got a slightly blurred effect in which the drops were discernable, although they ran together a little bit.

I found that the best results were obtained by operating the motor at its lowest possible speed. As a matter of fact, in nearly all my experiments, I found that the motor's lowest speed (approximately 1000 rpm) was too fast. I did, however, obtain excellent results through the use of a small propeller mounted upon another motor. I substituted a 150 watt lamp for the carbon arc lamp, and instead of a metal disk, I used a cardboard disk with two slits, 1/2" x 3/4". I found cardboard disks more satisfactory because, due to their lightness, they are more easily regulated. With this arrangement I got the propeller to stand almost perfectly still. There was, however, no doubt as to its speed, for the stroboscopic light touched upon all of the propeller except 1/2" at each end, and this section was a complete blurr.

In my experiments I used several disks, and I found that those with two or four slits were the most satisfactory. I tried one disk with a large, single slit in it, but it caused blurriness to appear in the target. Instead of a completely opaque disk, I substituted a circular dictaphone disk made of plastic. I had to abandon this method, since some of the light shone through the almost transparent plastic and cut down the sharpness of the image.

I was also able to obtain good results through the use of another motor upon which I mounted pieces of paper with various designs on them. These designs were specially constructed for experiments in the use of stroboscopic light. I was only able, due to the difficulty of keeping the motor I was using regulated, to make one of the five patterns which I tried appear perfectly motionless. On the others, however, I was able to make the designs appear to rotate in an opposite direction from that in which they were actually revolving, and also to get them very close to a complete standstill. These designs were definitely advantageous because of their size. Being small, I had no difficulty in illuminating the whole of their surface with the stroboscopic light.

I achieved fairly good results by employing an electrically operated vibrating string in one of my experiments. In this case, the vibrating string apparatus which I used was slightly inadequate for my purpose. The string did not vibrate the same all the time. I did get it to the point where the string was clearly visible at both the top and the bottom of its arc. Most of the time, however, I was unable to keep it completely stationary for any period of time. The best re-

sult I got with the vibrating string was a curved effect on the string, the curves being about 4" apart.

In all of my experiments except the one in which I used water drops, I used a home made carbon arc lamp. In comparison with the 150 watt bulb which I used on the water drops, the arc lamp was much more satisfactory as regards brightness. However, I found the arc lamp has its very definite disadvantages also. The light, while bright, sputters and produces extreme heat. By the time I had set up the rest of my equipment the arc lamp often had already gone out. Also, the odor from the burning carbon is rather unpleasant and the heat which is produced makes the apparatus too hot to handle most of the time. I want to attach a timing mechanism to the arc lamp which will automatically move the carbon rods closer together as they burn down.

For my future experiments, I intend to construct an electronic stroboscope. With this type of stroboscopic light, much better results can be achieved, and a greater area illuminated.

Chromatography

➤ MOVING LIQUIDS will carry material dissolved in them from one place to another. This fact is fundamental to chromatography. When the motion of the liquid is slowed up by trickling it through a long glass tube packed with some insoluble material, like clay, some materials are adsorbed by the fine particles of the solid packing, and left behind as the liquid moves on. In other arrangements, substances dissolved in one kind of liquid are separated and spread out by another solvent passing through the first at a different rate.

Since the minute particles of the dissolved material are free to move in the liquid, each kind of material tends to move at its own characteristic rate. Combinations of these various motions can be used to make a variety of separations. The young Science Talent Search winner, whose report follows, has combined centrifugal force with the other moving forces of chromatography to sort out metallic compounds, with their brilliant colors. He uses filter paper to support the reacting chemicals, and a simple turntable to accelerate the migrating ions.

The materials used in his project are solutions of metallic compounds which will react to give new compounds of contrasting colors.

Other applications of chromatography which make interesting demonstrations use solvents to separate brightly colored pigments found in the petals of flowers. Dahlias, zinnias and red roses yield mixtures of pigments which can be spread out in this way. Other substances that give good bands of color are grass, carrots, and paprika.

In addition to water, the various organic solvents, such as alcohol, acetone, xylene, and petroleum ether, should be tried for the best effect.

Centrifugal Technique

Edward P. Scanlon: A New Technique of Chromatographic Analysis. De La Salle High School, Minneapolis, Minn. Winner, 13th S.T.S., 1954.

➤ IN THE LAST fifteen years, the developments in the field of chromatography have been quite extensive. Out of the original adsorption chromatography have developed several different techniques Thus we have the Tiselius-Claesson method, paper chromatography, partition chromatography, and exchange chromatography. Although the theory underlying each of these methods is somewhat different, the apparatus employed is in most cases similar.

In the past six months, I have done some work on a new technique of chromatography. For lack of a better name, I will refer to it as "centrifugal chromatography" in the remainder of this paper. This method can be applied to the following other techniques of chromatographic analysis: exchange chromatography, adsorption chromatography, paper chromatography, or partition chromatography.

Up to the present time, I have limited my experiments to paper-partition chromatography. In the remainder of this paper I will describe my method of approaching the problem, the apparatus I have developed, and any results I have obtained or conclusions I have drawn. Possibly someone with more time and resources than I possess, will find it rewarding to take up a study along similar lines, and reach a conclusion as to the utility of the technique.

In original adsorption chromatography, the differentiation of the solutes depended on their distribution between a solid and a liquid phase. In partition chromatography, however, the differentiation is effected by the uneven distribution of the solute between two liquid phases. In this technique the solid column is retained but acts merely as a support for the immobile phase.

The use of filter paper as the support has become quite popular. The techniques most commonly used are: ascending chromatography, descending chromatography, and ascending-descending chromatography. Also a form of two-dimensional chromatography has been developed. In this technique the mobile phase is allowed to pass first in one direction, then the same or different liquid, is allowed to pass in a direction perpendicular to the first, thus effecting a two-dimensional chromatogram.

In centrifugal chromatography I employ filter paper as the support. In my original experiments I used only one liquid phase and the solid support. In my later experiments I employed two liquid phases and the solid support. Thus my first experiments were basically adsorption chromatography while the latter ones were partition chromatography.

My experiments have been confined to the separation of inorganic cations. In order to avoid the use of hydrogen or ammonium sulfide, I have confined my studies to those cations that can be made visible with some other de-

veloper such as potassium iodide or potassium ferrocyanide.

My apparatus at the present time consists of a small induction motor, a glass revolving plate, and a suitable stand. The glass plate is fastened to the axel of the motor and the whole unit is mounted on a box.

For supports I have used 12.5 cm. discs of Whatman No. 1 and No. 2 filter paper. These are moistened with water and placed on the glass plate. The motor is then started to spin off the excess moisture. The unknown solution is then applied to the paper. If it is used, the mobile phase is then applied. Finally a developer of some sort is applied.

The unknown may be applied in two ways. If there is a large amount of the solution it may be applied at the center while the plate is rotating. It then spreads out in a more or less even band. If only a small amount of the solution is available, it is applied in small spots at some distance from the center while the disc is at rest. This is done with a micro-pipette or a capillary tube. The ensuing procedure is the same in both cases.

For example a solution containing equal volumes of .1 M copper nitrate and .1 M ferric nitrate is prepared. The motor is started. When it approaches its maximum speed, three drops of the solution are applied at the center. After allowing it to run for about three minutes, a developer is applied. In this case the developer was potassium ferrocyanide. The result is a large blue zone surrounded by a narrow red zone. The former is ferric ferrocyanide. The latter is copper ferrocyanide.

As another example a solution containing equal volumes of .1 M cobalt nitrate and .1 M nickel is prepared. Four drops are applied at the center of the paper. This is followed by seven drops of dilute hydrochloric acid. After allowing the motor to run for about five minutes the chromatogram was developed with potassium ferrocyanide. The result was a green inner zone of nickel ferrocyanide and an outer zone of the somewhat lighter green cobalt ferrocyanide.

On both papers a light green colored zone is observed in the background. This is due to the developer. The zones are observed much more easily when held in front of a light.

The work I have done on this project has been very limited. Nevertheless I do not feel that the technique is totally hopeless. The fact that any separations are effected at all is encouragement to continue the work. Certainly a systematic analysis of the cations, following this principle, would greatly alleviate the work of inorganic analysis.

Still to be tried is the use of treated filter papers. Also it is feasible to substitute a shallow pan for the glass plate. This could be filled with an adsorbent or support, such as alumina or silica-gel respectively. The papers could also be treated with organic developers to bring out the zones, or observed under ultraviolet light or light of various colors.

I do not claim any revolutionary value for this new technique, but I do hope the idea may take its place, however small it may be, among the dozens of other techniques already developed. If this desire is realized, the work I have put in on the project will be well rewarded.

Photomicrography

Leslie Orloff: The Observation and Study of Microscopic Objects through Photomicrography. New Rochelle High School, New Rochelle, N. Y. Honorable Mention, 12th S.T.S., 1953.

➤ FOR A FEW years now I have been interested in both Photography and Biology. In my science project, I have been able to combine these interests and learn much in the process.

The first step was to acquire the necessary apparatus and to read books on photomicrography. During the latter part of this summer I had assembled everything and was ready to begin my work.

My first setup was one with the complete assembly in horizontal position. This was done by first laying the microscope horizontally, on a large flat table. Then I removed the objectives, eyepiece, substage condenser and mirror. About two feet from the microscope, I placed a microscope lamp so that the center of the light was directly in line with the center of the microscope tube. Between the microscope and light I placed a condenser with a $4\frac{3}{4}$ inch focal length, and lined it up so its center was in a straight line with the lamp and microscope tube.

In my next step, I placed the substage condenser, objectives and eyepiece in position. Using the low power objective (focal length 16 mm), I focused the microscope on a prepared slide and then adjusted the substage condenser until the image of the field condenser was in focus with the slide. This was easily done by placing a piece of paper on the field condenser and focusing on the paper.

My next object was to focus the light on the aperture of the substage condenser. I did this by measuring the distance from the aperture to the field condenser. This was $16\frac{1}{4}$ inches, — then I simply used the formula:

$$\frac{1}{F} = \frac{1}{D_1} + \frac{1}{D_2}.$$

Substituting $4\frac{3}{4}$, the focal length of the condenser, for F and $16\frac{1}{4}$ for D_1, I found D_2 to be a little less than $6\frac{3}{4}$ inches. I moved the light so it was that distance from the field condenser, and the image was situated perfectly. I then checked to see if everything was still in line. Lastly, I removed the eyepiece and closed the substage aperture until the light just filled the back of the objective. Then I replaced the eyepiece. Now I was ready to set up the camera.

I placed the camera on a stand which I had made, and adjusted it to the height of the microscope. Then, I opened the back and set it to be optically in line with the other apparatus. At this point, I took my first set of pictures. I focused the microscope to my vision and then set the camera focus at infinity. Then, with both the low power and high power (focal length 4 mm) objectives, I took test pictures for 10, 5, 3, 2 and 1 seconds, with a 10x eyepiece, of a slide of a sheep's spinal cord. To my surprise, these exposures were all too long. Some more test pictures showed that a half second exposure was sufficient.

These, and all other pictures taken with this horizontal arrangement, were on Kodak, 35 mm. plus-x panchromatic film. They were developed in Kodak microdol developer to achieve fine grain for good enlargements.

With this arrangement, I photomicrographed many prepared slides of plant and animal tissue, including slides of one celled animals which were obtained from my school's biology laboratory. However, with the microscope in a horizontal position, the stage could only hold prepared slides. I wanted to photomicrograph living specimens, which requires the microscope to be in a vertical position.

To do work with living specimens, I devised an entirely different arrangement of lighting, microscope and camera. Since excessive heat would kill the living specimens, precautionary methods had to be taken to avoid this. Also, a shorter exposure was necessary to stop motion. This could be done by using a brighter light and faster film. But, fast films are not fine grain, so larger film should be used to prevent having to make too great enlargements. For films, I used super xx panchromatic $2\frac{1}{4}$ x $3\frac{1}{4}$ cut film. I built a simple camera back for my enlarger and took the photomicrographs with this. The microscope was set up vertically and I was able to borrow a bright microscope light which had a condenser attached, simplifying adjusting and aligning.

The microscope was placed on the base of the enlarger and the light fit under the substage condenser. The bulb's condenser was its focal distance away from the filament. This emitted parallel rays of light which, when focused by the substage condenser, provided uneven lighting. To compensate for this, I moved the substage condenser to even the lighting. To keep out stray light, resulting from this compensation, from blurring the image formed on the film, I enclosed the aperture of the enlarger lens until it was just large enough to admit the image coming from the object. Before taking any photomicrographs, I checked the optical alignment and adjusted the substage aperture to admit only enough light to fill the objective. With this arrangement, I was now ready to photomicrograph any specimen that I could obtain.

From the Biology laboratory in my school I obtained several cultures, including one marked "mixed cultures." From this bottle I have taken most of my photomicrographs of living specimens. I observed one specimen, which I found in "mixed cultures," for about an hour, before taking a photomicrograph of it. At first, I could not identify it, but with the help of the Biology teacher, I found it to be a rotifer.

I have not yet photomicrographed the amoeba and paramecium in the living state. I plan to do that as soon as I can obtain the cultures. Also, during this year, I want to photomicrograph the organisms which inhabit pond water. One special undertaking which I plan is the photographing of Hydra. Since the animal is relatively large, all of it cannot be placed in the field of view with ordinary methods. I hope to correct this by removing the eyepiece and camera lens. Then, I will focus the image formed by the low power objective directly on the film.

➤ Problems in *topology formed the mathematical exhibit shown by Philip Zeidenberg, Science Talent Search winner in 1950. A one-dimensional Möbius Strip and a Klein Bottle, with the inside and outside one continuous surface, are shown on the table.*

Mathematical Constructions

➤ Exhibits in the field of mathematics are difficult to produce. The student has the problem of explaining his understanding of his chosen subject. It is unlikely that he has done something of great originality. His very competence in a subject regarded by many as too "hard to understand" is a handicap in planning something to attract the public, even the interested public accustomed to science exhibits. The choice the student must make, then, is whether to appeal only to the judges or to try for some of the more spectacular applications of mathematics. Excellent exhibits have been constructed starting with each of these aims.

The projects in mathematics represented in this book by one report and two photographs are on the spectacular side. They may be considered trivial by some young mathematicians.

They are by no means intended to discourage those who would prefer quite different demonstrations of their keenness in mathematical fields. These illustrate some of the classic problems in topology, always fascinating to the layman who finds a haunting mystery in the "fourth dimension."

Three-Dimensional Mobius Strips

Jerome Minkus: Three-Dimensional Möbius Strips. Erasmus Hall High School, Brooklyn, N. Y. Honorable Mention, 13th S.T.S., 1954.

➤ Consider a triangular prism which can be bent so as to make the end triangle A B C coincide with triangle A′ B′ C′ at the other end, thus forming a triangular ring, a three sided solid.

Let us go through this process again. This time, however, instead of making A′ B′ (of triangle A′ B′ C′) coincide with A B (of triangle A B C) let us make C′ A′ coincide with A B. Hence A′ B′ will coincide with B C and B′ C′ with C A. This is accomplished by giving one end of the prism a twist before fusing the two end triangles together.

We have thus formed a twisted triangular ring. Examination of the surface of this solid will show that it is unilateral. For, since C′ A′ and A B coincide and since these lines represent parallelograms A C C′ A′ and A B B′ A′ respectively, these two parallelograms must be connected and hence are one surface. Likewise since B C and A′ B′ coincide, parallelograms B C C′ B′ and A B B′ A′ must be one surface. Parallelograms A C C′ A′ and B C C′ B′ are also one because A C and C′ B′ coincide. Thus it can be seen that all three surfaces are one. This solid belongs to the class of solids which I call "Three Dimensional Möbius Strips."

For convenience we shall call A B B′ A′ surface 1, B C C′ B′ surface 2, and A C C′ A′ surface 3.

It can be seen that surface 1 (looking at triangle A′ B′ C′) is connected to surface 2 (looking at triangle A B C). In the same way 2 (triangle A′ B′ C′) is connected to 3 (triangle A B C), and 3 (triangle A′ B′ C′) is connected to 1 (triangle A B C). The above analysis indicates that from 1 we may go to 2, from 2 to 3, and from there back to 1 again. This will be represented by 1 - 2 - 3 - 1 . . . . This process can be continued indefinitely.

It is also possible to proceed in the opposite direction. In other words

1 - 2 - 3 - 1 . . .

This path is merely the first path backwards.

In the formation of the "triangular" Möbius Strip just discussed something which might be called a one-third twist was given to the triangular prism before fusing the two end triangles together. C′ A′ was made to coincide with A B. Suppose, however, we gave the prism a two-thirds twist before fusing the ends. Now B′ C′ would coincide with A B.

Utilizing the method previously described we find that the paths to be followed on this two-thirds twist triangular Möbius Strip are:

1 - 3 - 2 - 1 . . . and
1 - 2 - 3 - 1 . . . (backwards)

The paths on the one-third and two-thirds twist triangular Möbius Strips are basically the same. However, it should be noted that going in one direction on a two-thirds twist "triangular" Möbius Strip results in a path which is equivalent to the path resulting from going in the opposite direction on a one-third twist Möbius Strip.

A three-thirds twist is equivalent to fusing the end triangles of the prism without giving it any twist at all. No Möbius Strip is formed in this case.

It is evident that the prism used to form a three dimensional Möbius Strip need not be a triangular one. Quadrangular prisms, pentagonal ones, hexagonal ones, etc., may be used. The only restriction placed on the shapes of these various prisms (the triangular ones included) is that the end planes of each be regular figures, for if they are scalene they can not coincide after the prism is twisted.

Now go on to the Möbius Strips formed from quadrangular prisms. There are three twists which can be employed in making a Möbius Strip out of a quadrangular prism, namely; one-fourth, one-half and three-fourths.

Call the lateral faces of the quadrangular prism 1, 2, 3 and 4.

In tracing a path around the one-fourth twist quadrangular Möbius Strip we may use the same methods as those used in the case of the triangular Möbius Strips. Thus the paths which may be followed are:

1 - 2 - 3 - 4 - 1 . . .
and
1 - 4 - 3 - 2 - 1 . . .

The paths around the one-half twist quadrangular Möbius Strip are:

1 - 3 - 1 - 3 - 1 . . .
and
2 - 4 - 2 - 4 - 2 . . .

In this solid a path can be traced from one side only to the side directly opposite it. This Möbius Strip has the same surface properties as the ordinary "plane" Möbius Strip whose edges are considered as surfaces.

The paths around a three-fourths twist "quadrangular" Möbius Strip are:

1 - 4 - 3 - 2- 1 . . .and
1 - 2 - 3 - 4 - 1 . . .(backwards)

The three-fourths twist quadrangular Möbius Strip is to the one-fourth twist as the two-thirds twist triangular Möbius Strip is to the one-third twist, that is, going in one direction on a three fourths twist quadrangular Möbius Strip results in a path which is equivalent to the path resulting from going in the opposite direction on a one-fourth twist quadrangular Möbius Strip.

As the number of sides of a prism increases, the number of possible twists which can be employed in making a Möbius Strip out of that prism also increases. Whereas there are two possibilities for a triangular prism (1/3 and 2/3) and three for a quadrangular prism (1/4, 1/2, and 3/4, there are four possibilities for a pentagonal prism (1/5, 2/5, 3/5, and 4/5) and five for a hexagonal one (1/6, 1/3, 1/2, 2/3, and 5/6), etc.

The surface of any three dimensional Möbius Strip made from a prism with an odd number of lateral faces is such that any side can be reached from any other side, no matter what kind of twist is used in forming the Möbius Strip, except a full 360° twist. This is not true in the case of the Möbius Strips formed from a prism of an even number of lateral faces.

The ordinary "plane" Möbius Strip exhibits some unusual properties when cut. The three-dimensional Möbius Strip, not to be outdone, exhibits some even stranger ones. Suppose we were to take a knife and, starting on the middle of surface 1 of one-third twist triangular Möbius Strip, cut into the solid so as to bisect the triangular section.

Obviously as the knifeblade progressed, because all the sides of a triangular Möbius Strip are the same, it would eventually go from surface 1 to surface 2, next reaching surface 3. After this the knifeblade would return to surface 1 again, still theoretically cutting the middle of the surface. It is, therefore, needless to continue since no cut could possibly be made in the solid which has not been made before.

The triangular Möbius Strip appears to have been chopped into six smaller triangular rings, A, B, C, D, E, F. This however is not the case.

The one-third twist given the triangular prism before fusing the two ends together not only made the solid unilateral but also connected different parts of the interior of the prism. Section A is connected to C, which is connected to E. E in turn completes a ring by being connected to A. In like manner B, D, and F also form a ring. I strongly suspect (but cannot prove) that these two rings are intertwined. Neither of the rings can be a triangular Möbius Strip since the prisms from which they are made have right triangles for end planes. It was previously shown that no Möbius Strip could be formed from a prism having scalene end planes. The converse is also true. The cut just discussed is but one of many which can be made on a triangular Möbius Strip.

In the course of my studies I have had occasion to examine the different types of cuts which can be made on quadrangular Möbius Strips. Requirements for brevity keep me from entering my findings. However, I must say that the cuts made on a quadrangular Möbius Strip are just as interesting and much more complex than those which can be made on a triangular one.

In general it is true that the cuts become more complex as we go from pentagonal Möbius Strips to hexagonal ones, ad infinitum.

On this note I end my report on this most fascinating, although not very useful field — *"Three-Dimensional Möbius Strips."*

► THE PEAUCELLIER CELL *and Hart Inverter for constructing straight lines without a previous straight line as a guide were built by Paul J. Cohen, Stuyvesant High School, New York City, for his exhibit at the Ninth Science Talent Institute, in Washington, D. C. Paul was an S.T.S. winner in 1950.*

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